AD NUMBER
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AUTHORITY
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SUBIC

Submarine Integrated Control

OFFICE OF NAVAL RESEARCH

GENERAL DYNAMICS CORPORATION
ELECTRIC BOAT DIVISION
GROTON, CONNECTICUT

Best Available Copy

INTEGRAT FY '65 ASW SUBMARINE

AN ONR SUBIC STUDY

for the

Office of Naval Research (Code 466)

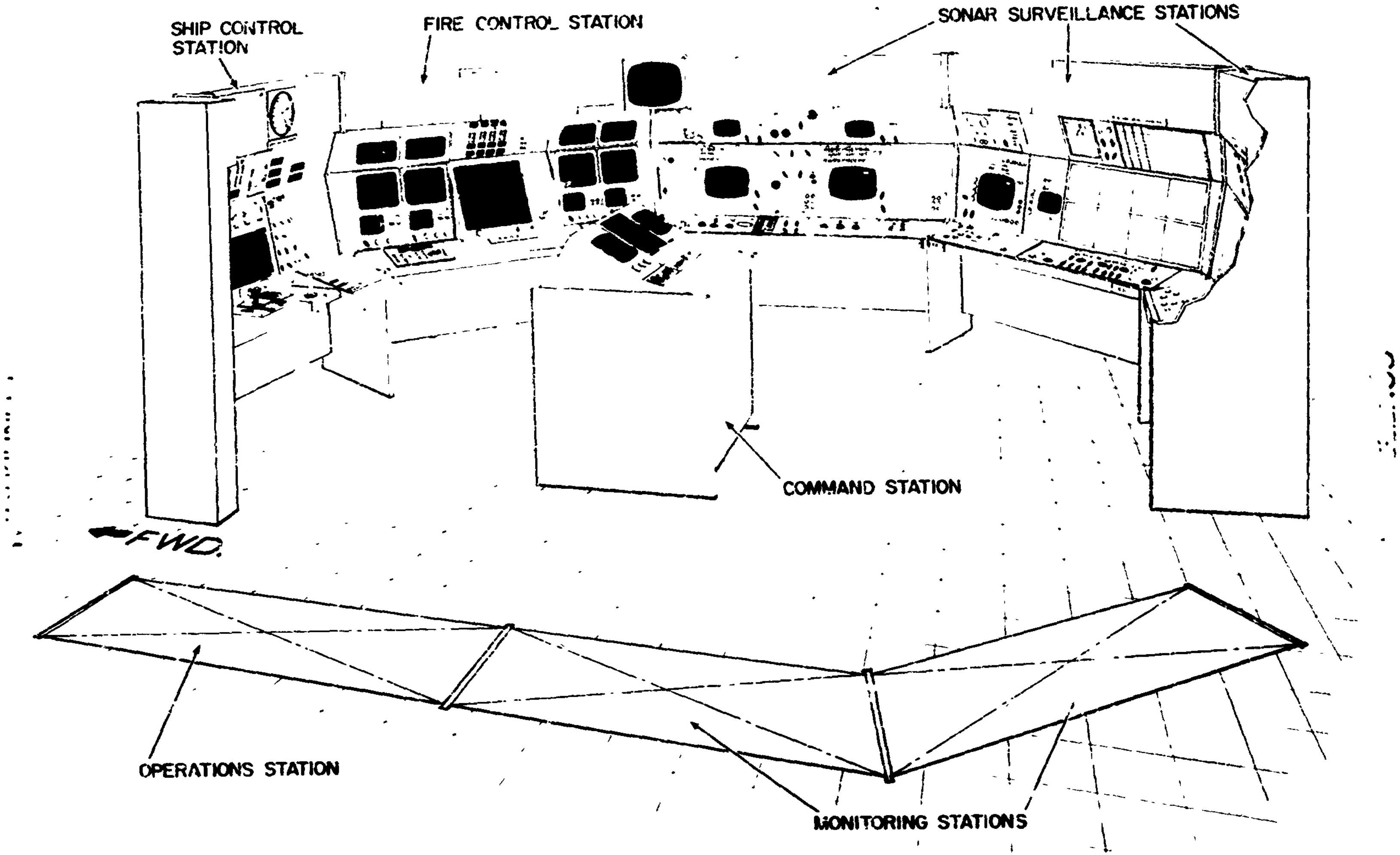
(Contract NOnr 2512(00))

requested by

BuShips-BuWeps

GENERAL DYNAMICS/ELECTRIC BOAT
Groton, Connecticut

C417-62-017
July, 1962



CONTROL ROOM ARRANGEMENT FOR FY-65 ASW SUBMARINE

FOREWORD

This report deals with the subject of system integration for ASW submarines. It has been prepared by the ONR-sponsored SUBIC program as an assist to the Bureau of Ships and Bureau of Naval Weapons. The Navy interest in system integration has been aptly expressed by Rear Adm. R. K. James, USN, Chief of the Bureau of Ships, in the April 1962 issue of the BuShips Journal:

> "With the objectives of obtaining optimum reliability of equipment, improving the technical capability of Bureau and shipyard personnel and ships' forces, and perfecting the integration process involving BuShips and BuWeps systems, important new steps are being taken. For example, the Bureau is issuing a directive establishing a new Combat Systems Division to provide improved electronics/weapon system services in each naval shipyard. I strongly urge that all personnel of the Bureau and its field activities, as well as our many private contractors in these technical areas, cooperate to the maximum extent in making the Navy's changeover from conventional armament to missile weapon systems a complete success in the shortest possible period of time."

It is with this cooperative spirit that this report of system integration in ASW submarines has been prepared and is submitted.

OVERVIEW OF THE STUDY

A. PURPOSE AND OBJECTIVES

The purpose of this study was to utilize the results of SUBIC research findings in control integration and computer data processing as a basis for the design of a control room for a FY'65 THRESHER-class submarine. The study was conducted under the auspices of the Office of Naval Research (ONR), although the specific tasks accomplished were requested by the Bureaus of Ships and Naval Weapons.

The task statements for this program may be briefly summarized as follows:

1) Construct a portable full scale mockup of SUBIC consoles, including panel face details, capable of fitting into a SS(N)593 control room.

2) Prepare an operational sequence (scenario) of a submarine operational mission in a number of typical situations in such detail as to provide a realistic test of the controls and displays to be devised for the stations in the mock-up.

3) Provide a succinct summary of computer recommendations contained in the SUBIC program with reference to FY'65 capabilities.

The objectives of the study were (1) to increase submarine effectiveness insofar as possible by control and display integration, (2) to determine the advantages of a central digital computer for such integration and also for data processing applications, (3) to provide control room station consoles which are technically feasible for the FY'65 submarine program, and (4) to demonstrate the operational feasibility of these consoles by evaluating them using the prepared operational sequences.

B. SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

To accomplish the objectives of the study, detailed analyses of functions, tasks, and information requirements were conducted for the

following areas: Ship Control, Fire Control, Sonar Surveillance, and Command. Less detailed studies of Monitoring and Operations Consoles were made also. Based upon these analyses the following results and conclusions were drawn.

The results of the study were:

1) The feasibility of the consoles was demonstrated by subjecting them to the operational sequence requirements which they satisfied.

2) All instruments and techniques incorporated in the console designs are or will be technically feasible by FY'65.

3) The number of personnel necessary to perform control functions has been reduced without consequent loss in effectiveness.

The conclusions drawn were:

1) All tactical control functions (except radio communications) can be accomplished using six stations in the control room.

2) Ship control functions can be performed by a single operator using display aiding techniques.

3) Improved fire control effectiveness can be obtained by providing techniques for direct utilization of the human in making target parameter estimates in the target motion analyses, and by the use of new data processing methods.

4) Sonar effectiveness in target detection and classification can be improved through the use of new methods of data processing.

5) Command functions can be facilitated by providing certain data which will aid tactical decision-making at a single station, viz. command and also by locating this station central to all operator stations.

6) A separate monitoring capability for all systems (outlined in the study) will materially increase equipment operational readiness time as well as improve tactical control.

Recommendations

It is recommended that further study be undertaken for the FY'65 submarine program to provide engineering specifications to implement the design developed by this study and to expand the effort to include other areas of the ship's functioning.

C. CONFIGURATION

The control room configuration consists of six control stations arranged in a circle with the command station located in the center of the complex. The command station is located such that the commander can easily observe and supervise his subordinates' performance.

Facing forward, five operator stations are formed roughly into a circle. Starting with the forward one, the stations are: ship control, fire control, sonar surveillance, monitoring, and operations. The command station faces forward (to the ship control console) and is located in the center of the control room.

Passageway is from aft center to the port side of the ship control console. Since tactical control (command, ship control, fire control, and sonar surveillance) are located forward and on the starboard side, through traffic should not disturb or interfere with operations.

The expected advantages of this arrangement are:

1) improved command capability since command can more easily supervise all systems;

2) more precise data is accessible to command; and,

3) fewer personnel are needed to perform control functions.

D. SHIP CONTROL

The ship control station is designed for one man control, under normal watchstanding conditions, of the major functions formerly associated with the steering and diving station and the ballast control station. Provision is made also for an emergency helmsman's station at the console in the event of a subsystem malfunction.

To facilitate one man control, automatic control and display-aiding techniques are provided for the two most demanding tasks performed at Ship Control: (1) steering and diving, and (2) trim control.

The console is designed around a primary Ship Control display, SQUIRE (Submarine QUIckened REsponse) which is used to control the course, depth and pitch of the ship via the planes and rudder.

The advantages of this console relative to stations now in operation are:

1) physical control over the submarine's position is centralized at a single station requiring a single operator

2) the use of display-aiding both for trim and steering and diving allows the operator to actively participate in both tasks while the tasks, themselves, are made less demanding

3) with SQUIRE, the operator can exercise better control of course, pitch and depth, using a single display.

An additional capability, . , ntrolling depth at zero speed is also provided.

E. FIRE CONTROL

The fire control station has been designed to incorporate the following major new features:

1) simultaneous handling of four targets and four weapons.

2) direct utilization of the human in making target parameter estimates in the computer localization solution.

3) visual detection of target zigs.

4) evaluation of localization solutions by means of calculated kill probabilities.

5) automatic determination and insertion of weapon control functions by the computer.

6) a means of solving the ambiguous consort triangulation problem.

The three main components of the console are a tactical display, four target analyzers, and a weapon and tube panel above the tactical display. The fully manned console (battle-stations) requires an operator for each of two analyzers, and a tactical display operator. The progress of target localization solutions and weapon preparations can be supervised by the attack coordinator from behind the seated operators.

F. SONAR SURVEILLANCE

Five operator positions are located at the sonar surveillance station: (1) passive initial detection, (2) frequency monitoring, (3) classification, (4) passive tracking, and (5) active tracking. Activities performed at the stations correspond to the several phases of the sonar surveillance mission, i.e., initial detection, classification, and tracking (active and passive).

The sonar-surveillance console major modifications can be summarized as follows:

1) The number of operator stations has been reduced from seven to five.

2) A Dimus-type pre-formed beam sonar system has been incorporated to provide passive initial detection data. This type of system provides (a) data from both broad and selected-fixed frequency bands; (b) the capability fc electing post-detection integration intervals; (c) continuous 360° detection; and (d) statistical testing for signal presence.

3) Demon and BSM recorders for presentation of refined frequency analyses have been added.

4) Passive ranging and active range and range rate analyses have been automated.

G. THE COMMAND STATION

The purpose of the command station is to provide information at a level of processing and in a form commensurate with the needs for command decision-making.

A Tactical Display automatically provides a bearing line for a target from own ship location, its bearing drift, speed, and contact designation as well as the target range and indication of target sig; geographic contours, and weapon range rings may be displayed with the controls provided at the commander's option. Another control provides the capability for the display of past targets or own ship tracks.

The Acoustic Detection Environment Display is an aid to depth selection; it can present probability contours indicating the detection capability of own ship or target. All of the possible contours may be for either of three detection probability levels (.5, .7, .9). Display inputs include characteristics of the environment (e.g. bathythermograph data), depth and figure-of-merit data. The former are inserted and processed by the computer while controls provide for the insertion of own ship and/or target characteristics.

H. MONITORING AND OPERATIONS STATIONS

These two stations, while not originally a part of this study, are included since integration of tactical control necessitates provision for these stations in the control room. Unfortunately, time limitations precluded the same detailed treatment accorded the other stations discussed.

The concept of a specialized, centralized area devoted primarily to monitoring is a new departure from present submarine practice.

Centralized monitoring will materially improve submarine effectiveness by: 1) ensuring better use of the computer for monitoring functions, 2) permitting both maintenance and performance monitoring, 3) allowing monitoring of many routine functions now monitored on other consoles thus reducing work loads at these consoles, 4) providing for redundant monitoring of certain critical items, and 5) furnishing more effective monitoring through special circuit design, computer utilization, and operator specialization. The tactical use of the Monitoring Console is that precise data on equipment performance furnished to command and other personnel in the control room will enable more effective use of the equipment systems monitored thus contributing to submarine effectiveness.

The operations station is incorporated to permit centralizing control of radar, ECM, navigation, internal voice communications, and the external TV periscope. The advantages associated with the Operations Console are: 1) provision of a control location for those functions essential to tactical submarine deployment not controlled elsewhere in the control room; 2) command may exercise direct supervision from his position, when these functions are controlled from this console; 3) inclusion of these tactical ship deployment functions at a central location is consistent with integration philosophy, whose aim is a single, integrated, tactical control system.

This console will incorporate facilities for the control of four general functions: 1) navigation, 2) ECM, 3) internal voice communications, and 4) remote monitoring of the TV and optical periscopes. The navigation function entails controls and displays for such systems as radar, Loran, SINS, and own ship's track, as well as geographical and star data and plotting facilities.

I. OPERATIONAL SEQUENCE ANALYSIS AND TESTS

One task of the current project was to prepare operational sequences corresponding to various phases of a THRESHER-class submarine operational mission. The purpose of these sequences was to test the feasibility of the various station consoles to determine if they satisfied

the requirements of the operational sequences. These operational sequences were comprised of lists of specific events which occur in a given submarine situation, arranged in order of occurrence. As used in this study, activities include verbal commands, responses to commands, inter-station communications, and operator actions.

The operational sequence utilized corresponded to four typical, and relatively independent phases or situations of a typical submarine mission. These were: 1) getting underway: process whereby the submarine leaves its anchorage and navigates through restricted waters to the point of diving; 2) Transit: the situation during which the submarine proceeds to its ordered station; 3) On-Station Patrol: the activities engaged in while patrolling on its assigned station; 4) ASW action: the situation in which a target is detected, identified approached, and attacked using any of a variety of weapons.

Since the sequence lists items of typical events and specific actions required to accomplish these events, it may be utilized to test console feasibility by ensuring that each console provides controls and displays which permit performance of each specific event within each of the four situations.

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I

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The Office of Naval Research (Code 466) in late 1961 offered to provide assistance as desired by the Bureau of Ships in the analysis of future system integration of ASW submarines. ONR has been sponsoring since 1958 a study effort, the SUBIC program (contract NOnr 2512(00)), which related directly to this problem. BuShips representatives availed themselves of the offer by requesting, on a 3-week time scale, an ONR SUBIC report which would assess the system integration possibilities for a fiscal '65 Thresher class ASW submarine. The Electric Boat Division, as prime contractor to ONR for project SUBIC, accordingly delivered the requested report (reference 1) on 25 September 1961. This report described 1) a fiscal '65 system which incorporated improved performance items, 2) an analysis of the system for the standpoint of performance, 3) an analysis of cost and equipment requirements, and 4) in as much detail as was then available, the operator's console panel-face layouts. It proposed a more comprehensive approach to system integration than was being suggested at the time by the BuShips-CSED (Coordinated Ship Electronic Design) program because a '65 rather than a '63 ship has been specified and the "minimum cost" constraint of the CSED '63 program had been relaxed for the purposes of this particular study.

Upon review of this initial ONR-SUBIC report (reference 1) the Bureaus of Ships and Weapons cooperated in the drafting of a new set of tasks. These tasks, transmitted through the Bureau of Ships to ONR, read as follows:

1) The Bureau of Ships desires that a subtask be assigned to the Electric Boat Division to make further study of the central computer complex. Provide a succinct summary of computer recommendations contained in SUBIC and other studies plus such additional study as may be required addressed toward the following:

a) A specific listing of the functional requirements for a digital computing center including those additional capabilities briefly discussed in the preliminary report dated 25 September 1961. These should be assigned a priority based on operational value to the performance of the ship and their contribution to the efficiency of the command loop system.

b) A closer analysis of the merit of the modular computer design versus multiple unit computer of the USQ-20/3 type (full back-up capacity). Relative cost figures for the accomplishment of each system on a single prototype installation and in follow-up quantities is desired. Particular emphasis is to be given the development effort, in time and cost, of intercommunication between modules in the modular concept.

c) A realistic feasibility analysis of the need for a central computer complex of either type in light of the findings of a) and b) to justify this portion of the SUBIC system.

2) Devise an operational sequence (scenario) of a submarine operational mission in such detail as to provide a realistic test of the controls and displays of a SUBIC control room in the following situations:

a) Getting underway
b) Piloting
c) Transit
d) Surveillance (air, surface, subsurface targets)
e) ASW action using all weapons (Cond. III)
f) ASW action using all weapons (Cond. I)
g) Selected casualties

3) Perform tests of the panel full size prints and the capabilities outlined in the 25 September report against the operational sequence devised in 2). Provide facilities for permitting similar tests of SUBIC concepts by fleet and Navy Department personnel.

4) Using information from 2 and 3 construct a portable full scale cardboard mockup of SUBIC consoles capable of being fitted into an SSN593 control room.

5) At the conclusion of 4 , describe the equipment required to instrument an operating version of the mockup, i.e., a breadboard SUBIC system.

6) Prepare suitable preliminary specifications for the equipment described in 5 .

Whereas SUBIC had previously concentrated on particularly critical system integration problems these new tasks clearly required a more comprehensive system analysis. Upon review, it appeared that the tasks could be accomplished on a 4" week time scale and the costs incurred would be considerably in excess of the amount allocated for the work from ONR SUBIC funds. The cost and time estimates had been derived on the basis of detailed PERT chart, developed by the Electric Boat Division and shown in Appendix A to this report. At a meeting at the Office of Naval Research on 3 November 1961, BuShips-BuWeps representatives accordingly requested a reduced scope of work by deletion of tasks items 1(b), 1(c) and 6 . A later agreement also resulted in deletion of task item 5 ("describe the equipment required to instrument an operating version of the SUBIC mockup, i.e. a breadboard SUBIC system") for the following reasons:

1) It was considered wasteful of material, money and manpower to recommend instrumentation of an operating version of the mockup in a superficial fashion, i.e., to instrument operator consoles so that lights and dials would operate but with no particular realism. It was felt that a demonstrator of this nature might well hinder program acceptance.

2) It was desired to avoid the implication that a more realistic simulation facility, of the type considered essential by the SUBIC program, could contribute to fiscal '65 submarine integrated system design. An appropriate facility should rather be viewed as a continuing research tool not geared to near-term shipbuilding programs.

This document, therefore, reports the studies which relate to the remaining tasks. A wealth of previously developed system integration material and submarine operator opinion has been drawn upon in generating the report. Although this study is an initial step only, it will be a valuable guide to future integrated system design and should be a logical basis for related discussions.

1.2 SUMMARY OF ACCOMPLISHMENTS

The most important elements of tactical submarine control have been integrated into a unified configuration placed around the Command Station. The configuration thus obtained provides for accomplishment of several major design objectives which will contribute to overall submarine tactical effectiveness

First, complete tactical control (excluding the engineering and exterior communications functions) has been centralized in a 20 x 20 foot area corresponding to the area available in the SS(N)593 THRESHER control room. The control consoles have been located in a semi-circle around a Command Station. The concept of a Command Station is somewhat of a departure from present submarine design. It is made feasible, in part, by the integration. While provision of a Command Station is in no way intended to imply that the commander is or should be restricted to this area during tactical submarine deployment, it does provide a location for the display of certain unique information for him.

Second, the arrangement of the control consoles enables the commander (or his delegated representative) to supervise directly each subordinate console operator. Thus, the commander can more readily delegate more responsibility to subordinates since his central location permits him to better supervise and interpose in a developing situation, if required.

Third, full advantage has been taken of the integration potentialities offered by digital computer capabilities. New displays, resulting from digital processing of raw data, on each of the consoles will materially increase the effectiveness of each of the control consoles in their performance of many associated control tasks. The commander from his central location has direct visual access to these data. The commander's decision-making tasks will thereby be greatly facilitated.

Finally, the arrangement of consoles within the control room and the capabilities for control they now afford will materially reduce the number of men needed for effective control. This has two obvious advantages: fewer personnel are needed in even the most demanding situations and, consequently, there will be less traffic and distraction in and through the control room. This, in itself, is a major accomplishment when compared with the present control room situation in a battlestations action.

A realistic operational sequence of an attack-class submarine has been developed from interview data and operational logs. The purpose for which the sequence was developed was to provide a "first test" of the feasibility of the control room arrangement and the console panel-face layouts. It constitutes one method of ensuring that all present functions are accounted for in the new arrangement. Moreover, when an operational sequence is sufficiently detailed, as in the present case, its use will go far towards preventing loss of functions which might otherwise occur in a major integration effort.

Since the operational sequence is a detailed exposition of a typical modern submarine mission, it should be of value to the Navy, apart from its application to the present study. It is, for example, illustrative of the types of events which typically can be expected to occur, the amount and kinds of interpersonal communication typical of four phases (situations) of an operational mission, the interrelationships of the control areas, and the responsibilities of command.

The operational sequence, therefore, can be used to provide considerable insight into submarine operational problems for non-submarine officers. Thus it is one of the significant accomplishments of this research program.

1.2.1 Methods Used in This Study

Six consoles have been designed as integral units of the control room. The consoles' designs resulted from the application of a particular method to the problems involved. The steps or phases of the method will be described briefly to indicate the common background from which each console was developed. Since each console presented certain unique problems and was limited by different equipment constraints, however, differing amounts of emphasis were placed on the steps of the method. For example, the command console design was limited by a lack of precise data on what information command actually needed, while, on the other hand, there was a considerable backlog of physical data from which to design the ship control console. The other consoles were somewhere between these two extremes. The methodological approach was as follows:

Mission Analysis

A mission analysis was undertaken for each area. This analysis consists of a precise definition of the purposes and intended uses of the console in question related to the overall mission of the submarine. It was based upon study of the submarine's intended mission, its operational capabilities, and the systems involved.

Systems Analysis

Following definition of the mission, a system analysis was undertaken to delineate the characteristics of each system. The analysis was based on an examination of systems and subsystems; the basic source data was the mission analysis and the actual operating systems. The result of this phase of the investigation was determination of operational system constraints.

Functional Analysis
After determination of the operational system constraints, the functions associated with each system were isolated by breaking down each system into the specific functions performed. Then using analytical methods a list was derived of the specific functions which each system must perform in order to accomplish its purposes. Results of this phase were the data which constituted the base for the remainder of the research.

Task Analysis
By a task analysis the functions were further broken down into the specific tasks which must be accomplished to perform the functions required.

Task Allocation
When all tasks associated with a specific system had been derived (in the preceding step), each separate task was assigned to either the human or the machine component of the system on the basis of whether the task is performed best and most reliably by the human or the machine. Numerous compromises were necessary because of the state-of-the-art in equipment design, work loads, computer capacity, and equipment constraints.

Information and Control Requirements
Based upon the task analysis and task allocations, the information and control requirements needed by the human were deduced. These requirements then constituted the data used to develop the console designs.

These console designs are a significant accomplishment of the present research program, since the level of integration achieved will:

1) permit centralizing all controls and displays associated with ship control, surveillance, fire control, and command in specific control consoles.

2) enable 6 to 9 men to control all functions in the normal cruise situation, and a maximum of 17 men in the battle-stations condition. Table 1-1 compares manpower requirements for present THRESHER-class submarines with those required for the new SUBIC control room configuration. The table shows that significant savings in personnel utilization has been obtained in both operational conditions. Table 1-2 shows the personnel now utilized by the THRESHER in the areas indicated.

3) utilize the digital computer to generate new displays which will make more effective the control exercised from the consoles.

An additional accomplishment of the study is the development of entirely new capabilities associated with each console. These capabilities, which are discussed in the appropriate sections below, greatly enhance the combat effectiveness of the submarine. Some examples are the SQUIRE display for ship control, improved target localization techniques in the fire control area, better classification and detection techniques in the sonar area, tactical displays for command and fire control which constitute new and powerful aids for tactical submarine utilization, the intercept course predictor system located on the operations console, and the monitoring capabilities provided by the monitoring console.

TABLE 1-1

PERSONNEL REQUIREMENTS

Station or Console	THRESHER-Class Normal Cruise	THRESHER-Class Battle Stations	SUBIC Proposed Design Normal Cruise	SUBIC Proposed Design Battle Stations
Ship Control	5	5	1	2
Command	1	1	1	1
Fire Control	1 (a)	10	1	4
Surveillance	2	7 (b)	1-3 (c)	5 (b)
Monitoring	-	-	1	3
Operations	1 (d)	4 (e)	1	2
Miscellaneous Personnel	1 (f)	2 (g)	-	-
TOTAL	11	29	6-8	17

Notes:

a. Roving forward watch available to operate F/C Firing Panel or other F/C equipment on emergency basis.

b. Includes sonar supervisor.

c. Depends on ship's policy, tactical situation, and mission.

d. Quartermaster.

e. May serve as additional personnel for F/C party.

f. I.C. electrician.

g. I.C. electrician and periscope assistant.

TABLE 1-2

THRESHER PERSONNEL ORGANIZATION

Normal Cruise			Battlestations
	Command		
Conning Officer	1	1	Approach Officer
	Ship Control		
Diving Officer	1	1	Diving Officer
Ship Controllers	2	2	Ship Controllers
E. Helmsman/Messenger	1	1	Emergency Helmsman
Ballast Control Operator	1	1	Ballast Control Operator
	Fire Control		
		1	Attack Coordinator
		1	Time Bearing Recorder
		1	Time Bearing Plotter
		1	Time Bearing Plot Operator
		1	Relative Motion Plot Operator
		1	Strip Plot Operator
		2	F/C Analyzer Operators
		1	F/C Panel Operator
Roving Fwd Watch		1	Narrative Recorder
	Navigation		
		1	Nav and Safety Plotter (Nav.)
		1	Nav and Safety Plot Recorder
Quartermaster	1	1	Quartermaster
		1	SS Radar/ECM Operator
	Misc		
IC Electrician	1	1	IC Electrician
		1	Periscope Assistant
	Sonar		
Operators	2	7	Operators & Supervisors
	11	29	

II

CONTROL ROOM ARRANGEMENT

2.1 DESCRIPTION AND ARRANGEMENT

The frontispiece and Figure 2-1 show the arrangement of the consoles in the control room. Five consoles (Surveillance, Fire Control, Ship Control, Operations, and Monitoring) have been placed in a modified circular arrangement with the Command Station in the center. The control room occupies an approximately 20 x 20 foot useable area, extending completely across the ship at the upper deck level. Through passageway is from the center aft to the portside of the Ship Control Console. Access to the bridge is via the portside passageway.

Design of the control room configuration was developed utilizing the following guidelines:

1) All tactical control facilities should be centralized in the control room.

2) Command should have maximum capabilities for direct supervision of the total tactical control facilities for which he is responsible.

The basis for guidelines 1) and 2) is that submarine effectiveness is directly related to the ease and speed with which control data are made available to the users for decision-making and for action. Both decision-making and action taken will be improved when direct links of critical subsystems are available to command.

3) The digital computer's full capabilities for aiding tactical control can best be utilized by integrating the several subsystems into a unified centrally-located system convenient to the commander.

In this case, computer data processing allows better summation of raw data, improved data displays, introduction of new types of data resulting from statistical processing, and improved automation capabilities. When these facilities are appropriately combined,

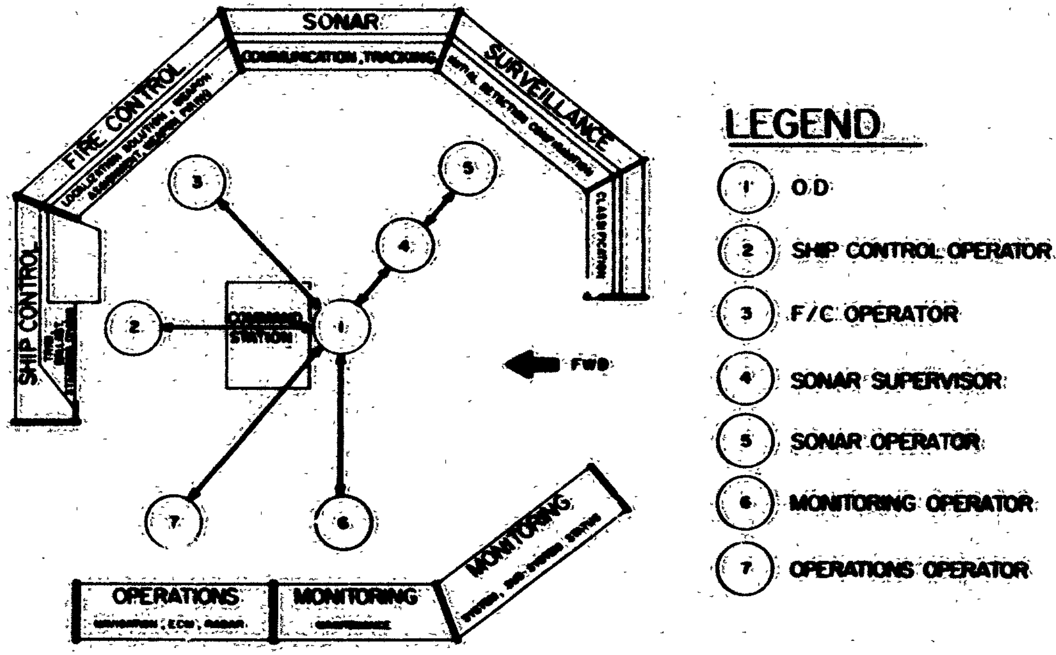

FIGURE 2-2 CONTROL ROOM ARRANGEMENT, PLAN VIEW

the purposes specified in 1) and 2) above will be achieved; space and size requirements for control-display equipment will permit integration into a single overall system.

4) Reductions in manpower, through traffic, and visual and auditory distractions (in battlestation action, particularly), can be obtained by integration and improved control-display capabilities.

The digital computer will reduce the manpower requirement by performing many of the routine functions now performed by man and, in addition, providing new capabilities in display and automation areas. If manpower is reduced, both traffic and distraction can be reduced by suitable station arrangement.

Since maximizing command effectiveness was a major design goal, the Command Station was located in the center of the arrangement. From this position the commander or his representative has the best location for overall supervision of each of the subordinate stations. The Command Station has been designed to facilitate this supervision. The commander or his representative is, therefore, ideally situated to utilize both the displays at this station and supervise subordinates at each of the consoles.

The Ship Control Console is located against the compartment's forward bulkhead directly in front of the Command Station. This location provides the best location for the ship controller in that it maintains the right-left control relationship with the direction of ship travel. Its location is such that command may easily monitor the controller's behavior and response to orders.

Angled at 45° to the right of the Ship Control Console is the Fire Control Console. Placing this console next to the Ship Control Console will enable command to monitor both areas more effectively during combat.

The Surveillance Console is located to the right of the Command Station and adjacent to Fire Control. This places the three subsystems needed

for torpedo action (Command, Fire Control, and Surveillance) together. With Ship Control Console directly forward, command has available on his right and forward all data needed for maneuvering the ship and launching weapons.

Since traffic through the control room moves to the left of the Command Station, messengers and other personnel, who must go through the control room, will not interfere with tactical control or distract operating personnel.

Aft of the forward passageway on the port side of the control room is the Operations Console. This station will control radar, ECM, navigation, and interior communications. Since these functions are intermittent, this station would be used infrequently during attack situations, except when radar rather than sonar was used to furnish data to fire control. With improvement in sonars, it is expected that radar will be most frequently used for navigation only. Nevertheless, the capability of utilizing radar for fire control has been maintained for the infrequent need. In this situation, command will have the capability of supervising the three forward stations (Operations, Ship Control, and Fire Control) during attack operations.

A Monitoring Console is located aft of the Operations Console. This console provides for monitoring of critical operations and status displays. It will furnish command with precise data on equipment operation and performance degradation. Since data on this console are used by command on a demand or as-needed basis, it can be appropriately located out of the more critical attack control areas.

2.2 ADVANTAGES AND EXPECTED GAINS

The preceding discussion has indicated some of the advantages associated with the proposed arrangement. We may summarize the advantages and expected gains of the proposed configuration as follows:

1) Improved tactical effectiveness, since all elements of tactical control have been centralized into one area.

2) Improved command control, because command can more readily supervise all systems.

3) Better data for command decision-making, because of data-processing and direct availability of essential data.

4) Reduced traffic flow distractions inasmuch as the arrangement permits through traffic without interfering with essential operations.

5) Improved command decision-making in regard to operational readiness and systems capabilities, which results from incorporation of the new monitoring capability (for example, better estimates of how much time is needed to make failed equipment operational or the precise amount of equipment degradation from optimum).

6) Greater control effectiveness as the result of the configuration (which allows more direct supervision) and due to the level of integration achieved at each console.

7) Improved operation, resulting from incorporation of the digital computer as the central integration tool.

8) Better utilization of fewer personnel than are presently required due to the increased capabilities listed above.

Based, therefore, upon these expected advantages of the proposed configuration, it is entirely reasonable to expect that overall combat effectiveness of the submarine will be materially improved.

CONFIDENTIAL

III

SHIP CONTROL

3.1 PREFACE

The purpose of this ship control section is three-fold:

1) to determine the requirements for a Ship Control Station of an attack class submarine through an analysis of station functions, operator tasks, and information inputs necessary to accomplish the tasks specified

2) to utilize the analysis performed in 1) above to provide human factor inputs to the design of a Ship Control Station Console for the FY'65 attack class submarine

3) to demonstrate the feasibility of the station through use of relevant portions of an Operational Sequence Study.

3.2 INTRODUCTION

The primary mission of the attack class submarine, which is considered in this report, is to conduct anti-submarine warfare (ASW) and to destroy targets of opportunity. To accomplish these missions, the submarine is provided with capabilities for locomotion, navigation, detection, fire control, and communications. Owing to the complexity of the submarine as a weapon system, these capabilities are organized around operator stations to which are assigned a specified number of related functions corresponding to some aspect of the total mission (for example, maneuvering, detection, and target solution analysis).

Control of all functions is the ultimate responsibility of the commander and, in this respect, all stations other than command are primarily operator stations and not decision-maker stations. As such, each station operator serves the commander as an information source from which he can obtain data to aid him in selecting courses of action and also

as an effector link to machine components, which means the operator serves as the relay between command and a control action.[1]

In order to increase the effectiveness of submarine operations, the effectiveness of each station complex (man-machine subsystem) must be optimized. This requires that each station be designed to reflect the capabilities of both human and machine components comprising it such that all delegated functions can be accomplished most effectively. To achieve this goal, it is necessary to periodically re-examine, for each station, the roles played by human and machine components to discover whether or not an optimal assignment of tasks has been made. This is especially true for the human component since, in general, a major restriction on realizing any potential increase in system effectiveness is the presence of the human operator performing tasks which might be handled more adequately by machine components.

Compared to machines, man is extremely variable in his behavior. Variability is often desirable because it reflects adaptability (flexibility) to unusual conditions, but is also often undesirable because it is indicative of man's limited ability to perform tasks which require accurate differentiation and/or integration of subtle information, for example, rates and accelerations.

The skills required to perform tasks involving the determination of rate and acceleration information can be acquired through training and

[1] This is not to imply that each station operator is solely an information transmitter and effector link for command. Currently, some autonomy of action is permitted at each station and this is a trend which will probably continue as future submarines become even more complex. The degree of decision-making authority, however, will vary from station to station under both normal and emergency conditions. In general, this authority for independent action will be delegated directly by command or prescribed in the regulations and will be based, ideally, on a policy decision exercised prior to the formalization of the station complex.

experience, but the level of accuracy and repeatability achieved by machines can rarely be approached by man. For just this reason, the maximum increase in system effectiveness possible is dependent upon the boundary conditions, sensory and conceptual, imposed by the human in the system.

One method of mitigating the effects of unwanted human variability on system effectiveness is to assign, where possible, those task aspects which severely tax the human's sensory or conceptual abilities to machine components through the use of automatic control techniques. Another method, related to the first, is to examine those situations in which operator involvement is deemed necessary or desirable (machine substitution is not feasible or warranted) to determine the type of information inputs to optimize his performance.

Thus, to attain the goal of increasing system effectiveness by utilizing techniques which increase the effectiveness of the human components, it is necessary to examine that aspect of the total mission which corresponds to the objectives of the particular station under study. From this examination, the functions appropriate to the station can be defined and the tasks associated with these functions specified. In addition, for those tasks performed by the human components, the necessary information inputs can be determined. These, in turn, can be used as the basis for selecting appropriate display and control concepts and, ultimately, actual displays and controls. The purpose of this portion of the study is to accomplish these objectives for one submarine station, Ship Control.

3.3 SHIP CONTROL ANALYSIS

3.3.1 Assumptions and Constraints

The following assumptions and constraints specify the limiting conditions for the analysis:

Assumptions

1) The Ship Control Station is basically an operator's station and not a decision-maker's station. Thus, inputs to the system come

largely from command and, in turn, system outputs satisfy such things as tactical or navigational requirements.

2) Current methods of controlling ship's position (for example, the use of variation in the position of control surfaces (planes and rudder)) will continue to be employed for some time in the future.

Constraints

1) The analysis of functions and tasks will be limited to those currently involving operator participation. Machine tasks (for example, data processing and environmental sensing) will not be considered in detail.

2) To permit maximum flexibility of operation, provision will be made for possible manual control of those operator tasks reassigned to machine components.

3) Engineering requirements for operator and machine tasks will not be considered here, but will be treated elsewhere.

3.3.2 Ship Control Mission

The Ship Control (S.C.) station is concerned with the locomotion aspect of the submarine mission. As such it serves as the effector link for command in the tactical and navigational deployment of the vessel. The S.C. operator(s), in turn, is charged with the responsibility of effecting changes, which are initiated from command in the spatial attitude, spatial orientation, and velocity of the vessel (i.e., changes in the location and movement of the submarine within its three-dimensional vironment). To discharge this responsibility, the S.C. station must serve three major functions.

1) Depth Control
2) Course Control
3) Speed Control

Each function is described, in the following section, as if it were independent of all others. This approach is used for convenience only, since in actual fact the functions are interrelated.[2]

3.3.3 Function Descriptions

1) Depth Control

This function encompasses those tasks performed to maneuver the submarine in the vertical plane. At present, depth control is accomplished by means of control surface manipulation (movement of the planes) and by changing the amount and/or location of water ballast carried aboard ship.

2) Course Control

This function encompasses those tasks performed to maneuver the submarine in the horizontal plane. At present, course control is accomplished by means of control surface manipulation (movement of the rudder).

3) Speed Control

This function encompasses those tasks performed to control the velocity of the submarine. At present, speed control is not accomplished directly at the S.C. station but at some other station (for example, the maneuvering room). Speed orders are communicated from command via S.C. to the speed control station and compliance to orders is monitored at S.C.

3.3.4 Task Descriptions

The tasks described in this section are those involving operator participation. Most of these relate to the three ship control functions described previously, but miscellaneous tasks now performed at this

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[2] Both depth and course control are influenced by own ship's velocity and there are cross-coupling effects between planes and rudder, the importance of such effects being highly dependent upon speed.

station are discussed also. The approach followed is to describe each task and the current activities engaged in by the operator to accomplish them.

3.3.4.1 Depth Control

There are four distinguishable tasks subsumed under this function.

1) Submerging (initial descent from the surface to some ordered depth)

2) Surfacing (ascent to the surface from some operating depth)

3) Depth-Seeking (changing depth while submerged)

4) Depth-Keeping (maintaining a specified depth and steady state pitch (trim) angle while submerged)

3.3.4.1.1 Submerging - To submerge, the operator(s) must establish a condition of neutral buoyancy suitable for subsurface travel. To establish the condition, he must modify the initial positive buoyancy condition existing for surface travel by making a gross adjustment in the water ballast. By increasing the amount of water ballast, a negative buoyancy condition is created. Coordinated with the deflection of the depth control activating surfaces (planes), this produces a dive from the surface. Prior to executing this maneuver, the operator must ascertain that those hull accesses which are normally open on the surface are closed to prevent flooding the ship. At some point after initiating the dive, he must counteract the action of the planes so that the submarine levels off at a previously specified depth. At this time or sooner, depending upon the hydrodynamics of the ship, he may have to make an additional adjustment in the ballast supply to achieve a neutral buoyancy condition appropriate to the new operating depth.

The activities engaged in to accomplish this task are as follows:

1) Securing the ship, i.e., making sure that all hatches, hull openings and induction and exhaust valves are closed. Certain of these openings are closed locally. The S.C. operator must monitor the closing of locally operated openings and close those openings controlled at S.C.

2) Flooding MBTs. The Main Ballast Tanks System (MBT) is used to provide the large change in weight overall necessary to submerge. These tanks are non-pressurized and to flood them the operator will vent the tanks, releasing the air trapped in them. Sea pressure will force open the flood ports and the tanks will flood.

3) Planing down to the ordered depth. The operator will deflect the planes to put a down angle on the ship. This will result in a pitch rate being generated which will produce some pitch angle. At some time subsequent to the initial control action, a depth rate will develop and eventually an excursion in depth. At some time prior to reaching the desired depth, the operator will initiate reverse control action to reduce pitch angle, pitch rate, and depth rate to zero at the ordered depth.

4) Adjusting the Negative Buoyancy Tank (NBT). This tank comprising the Special Ballast System is a pressurized tank possessing a true flood valve (unlike Main Ballast Tanks) which allows adjustments to be made in the level of water in this tank over a wide range of depths. Normally, this tank is carried full on the surface or flooded when submerging. Under certain conditions, the combined weight gained by flooding the MBTs and the NBT is greater than the amount needed to obtain a neutral buoyancy condition suitable for the operating depth. The usual procedure, when this condition exists, is to adjust the amount of water in this tank to some level sufficient to attain neutral buoyancy. This level is generally calculated in advance and the operator will expel the excess water using high pressure air; the operation is called "blowing to the mark." As use of the high pressure air system results in large changes, fine adjustment of the water level can be effected using a pump system also connected to this tank.

3.3.4.1.2 Surfacing - To surface, the operator must establish a positive buoyancy condition for the ship. To do this, he adjusts the amount of ballast to approximately the same level that was in effect prior to

submerging. Coordinated with the inclination of the planes this will result in the submarine surfacing.

The activities engaged in to accomplish this task are as follows:

1) Blowing MBTs. High pressure air is used to blow these tanks. The operator activates this system which is connected to the MBTs. At present, to conserve the high pressure air supply, this system may be de-activated at or near the surface and low pressure air entering the ship through the hull openings can be used to complete the emptying of the tanks.

2) Planing up to the surface. The operator will deflect the planes to produce an up angle on the ship. In all respects, except for the direction of travel, the control action taken is the same as for submerging.

3) Adjusting the NBT. In general, no adjustment in the ballast supply of this tank is made while surfacing, although the tank may be re-flooded at the surface.

3.3.4.1.3 Depth-Seeking - For the more common case, to change from one subsurface depth to another, the operator will utilize his planes.[3] Two sets of planes are provided on most ships.

1) the stern planes located to the rear of the ship; these are used to produce the angles on the ship (pitch angles) necessary for fast depth changes and

2) the fairwater or sail planes located close to the center of gravity; these are used to produce the moment forces necessary for slow changes in depth, theoretically without generating any pitch

[3] No truly general statement can be made since optimal maneuvering may require planes action, changing speed, and/or transferring water.

angle. Policy differs from ship to ship on whether to use them singly or in combination, but, in general, the fairwater planes are more effective for changing depth at low speeds while the stern planes are more effective at high speeds. In addition, in changing depth at high speed, the fairwater planes can be used as a brake on the action of the stern planes.

The activities engaged in to accomplish this task are as follows:

1) Planing up (down) to the new ordered depth. The operator will manipulate one or both sets of planes to accomplish a depth change. The control actions taken are comparable to those described for the submerging and surfacing tasks.

3.3.4.1.4 Depth-Keeping - To maintain an ordered depth once achieved the operator has recourse to planes manipulation, water transfer, or both. Under ideal conditions of neutral buoyancy (weight overall) and neutral trim (fore and aft weight balance)[4], the operator will use the fairwater planes to hold depth and the stern planes to hold some desired steady state pitch angle. If a weight imbalance occurs, however, corrective action must be taken. Some degree of deviation from neutral balance can be compensated for by means of control surface bias aft (stern planes deflection). This method of compensation is less effective than ballast adjustment at low speeds and is completely ineffective at zero speeds (hovering). Under these conditions, adjustment in the ballast supply is required to maintain depth. In the same way, small discrepancies from neutral trim can be compensated for by an appropriately selected pitch angle, given a speed in excess of some critical value which differs from ship to ship. Extremely large deviations must be compensated by adjustments in the ballast supply.

[4]Neutral trim is that condition for which the distribution of weight overall is sufficient to maintain zero depth rate, which is usually about zero pitch.

The activities engaged in to accomplish this task are as follows:

1) Holding depth. To maintain depth, the operator will deflect the fairwater planes to eliminate any moment forces acting to change depth. If necessary, he will deflect the stern planes to compensate for deviations in neutral buoyancy and/or neutral trim.

2) Holding Pitch. To hold some steady state pitch angle (zero or otherwise) the operator will deflect his stern planes.

3) Effecting Trim.[5] The Variable Ballast System is used to effect trim. This system consists of four tanks, five including the NBT. The adjustments made in these tanks are generally small relative to those made to establish the initial condition of neutral buoyancy. The type of imbalance existing may be of three kinds. These are: (1) a deviation in weight overall, heavy or light, resulting in a depth rate being produced, (2) a deviation in the distribution of weight, forward, aft or midship with overall weight neutral, resulting in a steady-state pitch (for fore or aft imbalance) or a list (for midship imbalance), and (3) a combination of (1) and (2) above.

To correct trim, the operator must determine the kind of imbalance existing including its location and the amount of this imbalance. He does this by converting, in some fashion, the amount of planes angles he is using to hold depth and pitch to a value of weight heavy or light, forward, aft, or overall. Starting with this estimate, he will transfer water from: (a) the sea to one or more of the tanks, (b) one or more of the tanks to the sea and/or (c) from tank(s) to tank(s); the transfer of water is effected via a

[5]Effecting Trim is the designation for the activities engaged in to bring the ship to a condition of neutral buoyancy and neutral trim. Factors affecting these conditions which must be compensated for are changes in thermal gradients, emptying sanitary tanks, pumping bilges, etc.

pump system. He will continue the foregoing process until he or the O.O.D. is satisfied that trim has been effected.

3.3.4.2 Course Control

There are three distinguishable tasks subsumed under this function.

1) Piloting: this task can involve adjusting own ship's course to avoid geographical obstacles (while surfaced or submerged), enter or exit from a docking area (surfaced), or maneuver in enemy waters (submerged).

2) Course-Seeking: this task involves changing own ship's course, always from one course (heading) to another.

3) Course-Keeping: this task involves adjusting own ship's course to conform with an ordered course or maintaining a position relative to another ship (for example, staying in formation); the latter will probably involve changing speed as well.

The activity engaged in by the operator to accomplish all of these tasks is the manipulation of the rudder. To effect a course change, for example, the operator will position his rudder to some angle, depending upon the speed of own ship; this will result in a rate of turn for own ship and, eventually, a course (heading) change.[6] To effect a course change in optimal time with minimum overshoot, the operator will have to initiate reverse control action to reduce rudder angle and turn rate to zero at the ordered course.

3.3.4.3 Speed Control

To change speeds, adjustments must be made in the propulsion equipment, for example, changing shaft speed. At present, control over the propulsion equipment is accomplished locally. To change speed, the

[6] In general, piloting will involve both seeking and keeping course. The actual determination of course and speed is not accomplished by the S.C. operator, but by the O.O.D.

commander orders a change either in standard nautical terms or in actual rpm. The S.C. operator serves as the relay for this order and communicates it to the speed control station; he then monitors compliance to the order.

3.3.4.4 Miscellaneous Ship Control Tasks

Associated with the S.C. station are a number of tasks, some of which are only indirectly related to the three functions considered to be areas of responsibility for this station. In general, these tasks can be classified as follows:

1) Energizing Tasks. These involve activating all indicator and control subsystems utilized in ship control. The activities engaged in by the operator are turning on the power to these subsystems and, when necessary, testing the power to individual components.

2) Regulatory Tasks. These involve monitoring and regulating the status of the several hydraulic power systems, air banks, and various alarm indicators, for example, hydrogen and flooding. The activities engaged in by the operator are monitoring on-line system and, when necessary, changing from one system to another, for example, switching air banks.

3) Control Tasks. There are two such tasks currently performed at ship control. These are: (1) operation of the Snorkel System which involves the coordination of the snorkel mast system, when it is utilized to operate engines, charge the batteries or ventilate the ship. The activities engaged in by the operator are raising and lowering the snorkel induction mast, aligning the various valves and hull openings associated with this system, and monitoring watertight integrity; and (2) controlling position of masts, which involves raising and lowering all ships masts.[7] The

[7] Lowering controls for some masts are provided at the stations which use them, but control over lowering is possible at Ship Control.

activities engaged in by the operator are effecting orders to raise and/or lower masts.

For illustrative purposes, the current ship control tasks are summarized in Table 3-1 below. For some of the tasks, the control responses made by the operator(s) can be specified fairly completely by stating the generic class of control action taken. In other cases, this is not possible and a more detailed disucssion of these responses is presented in the following section.

3.3.5 Task Analyses

The tasks described in the preceding section are operator tasks and constitute the tasks currently performed at Ship Control. To accomplish these tasks, two manned stations comprising Ship Control are employed. These are the Steering and Diving (S. and D.) Station and the Ballast Control (B.C.) Station. The former station is manned normally by two operators (fairwater planesman and stern planesman), one of which also controls the rudder. Provision is made for a third operator, the emergency helmsman, who will control the rudder when separate control of the three activating surfaces is deemed necessary. The only other task performed at this station is ordering speed changes.

The B.C. Station, manned by a single operator, is responsible for depth control via water transfer, operation of the snorkel system, ensuring watertight integrity, raising and lowering of masts, and the regulatory tasks, for example, energizing power systems and switching airbanks. With the exception of the depth control tasks assigned to the B.C. Station, all tasks directly related to the primary mission of Ship Control (locomotion of the vessel) are assigned to the S. and D. Station. All of the other operator tasks assigned to the B.C. Station are, for the most part, regulatory in nature.[8]

[8] The B.C. operator also serves as Chief of the Watch (C.O.W.) and, in some cases, O.O.D. on present attack class submarine, making this a very responsible position. However, the operator tasks he performs are limited to those discussed.

TABLE 3-1

SUMMARY DATA FOR THE SHIP CONTROL TASKS CURRENTLY INVOLVING OPERATOR PARTICIPATION

Station Task	Operator Task	Control Response(s)	Task Characteristic	Comment
Submerging	ensuring water-tight integrity	remote closing of certain hull openings	discrete control action	
		monitoring status of locally closed openings	visual inspection of indicators	is critical for own ship safety
	flooding MBTs	opening vents	discrete control action	
		closing vents	discrete control action	
	planing down	selecting ordered depth*		
		selecting pitch angle or rate of descent*	judgments based on ship's procedures	
		selecting speed*		
		manipulating stern and possibly fair-water planes	continuous control action	involves control of a higher-order system requiring a high degree of perceptual motor skill**

*Normally, these parameters are chosen by commander or O.O.D.
**A higher-order system is one in which a number of integrations intervene between control action and system reaction.

TABLE 3-1 (Cont)

Station Task	Operator Task	Control Response(s)	Task Characteristic	Comment
	adjusting NBT	selecting net buoyancy level**	judgment based on ship's procedures	
		blowing tank (gross adjustment) and/or pumping out tank (fine adjustment)	discrete control action	
Surfacing	blowing MBTs	activating high pressure air system and/or low pressure air system	discrete control action	
	planing up	selecting pitch angle or rate of ascent	judgments based on ship's procedures	
		selecting speed		
		manipulating stern & possible fairwater planes	continuous control action	involves control of a higher-order system requiring a high degree of perceptual motor skill
Depth-Seeking	planing up (down)	selected ordered depth		
		selecting pitch angle or rate of ascent (descent)	judgments based on ship's procedures	
		selecting speed		

*Normally, desired water level predetermined.

TABLE 3-1 (Cont)

Station Task	Operator Task	Control Response(s)	Task Characteristics	Comment
Depth-Seeking (Cont)		manipulating stern & possibly fair-water planes	continuous control action	involves control of a higher-order system requiring a high degree of perceptual motor skill
Depth-Keeping	holding depth	manipulating fair-water and possibly stern planes	continuous control action	same as above
	holding pitch	manipulating stern planes	continuous control action	same as above
	effecting trim	determining trim imbalance	interpretation of indicators	
		calculating amount of water to be transferred and location	computation	involves translation of rate & angular information to quantitative estimate of water imbalance requires high degree of computational ability
		pumping water in or out of certain trim tanks	discrete control action	
Piloting	adjusting course to avoid obstacles	selecting course (heading)		
		selecting speed	judgments based on ship's procedures	
		selecting rudder angle		

TABLE 3-1 (Cont)

Station Task	Operator Task	Control Response(s)	Task Characteristics	Comment
Piloting (Cont)		monitoring geographic environment	visual inspection of environment	is accomplished by command using charts or displays
		manipulating rudder	continuous control action	involves control of a higher-order system requiring a high degree of perceptual motor skill
Course-Seeking	turning ship	selecting course		
		selecting speed	judgments based on ship's procedures	
		selecting rudder angle		
		manipulating rudder	continuous control action	same as above
Course-Keeping	holding course	manipulating rudder	continuous control action	same as above
Speed-Ordering	regulating speed	communicating speed orders	discrete control action	
		monitoring compliance	inspection of indicators	
Miscellaneous Energizing Tasks	activating control and indicator sub-systems	switching on power supplies	discrete control action	
	testing power	testing sub-systems e.g., deflecting planes	discrete control action	

TABLE 3-1 (Cont)

Station Task	Operator Task	Control Response(s)	Task Characteristics	Comment
Regulatory Tasks	maintaining on-line air and hydraulic pressure systems	monitoring status of systems	inspection of indicators	
		changing on-line system	discrete control action	
	monitoring internal environment, e.g., hydrogen level	monitoring alarm indicators	visual inspection of indicators	
		reporting unsatisfactory condition	verbal communication	
Control Tasks	operating Snorkel System	raising (lowering) snorkel mast	discrete control action	
		aligning valves & hull openings	discrete control action	is demanding of operator's time
		monitoring watertight integrity	visual inspection of indicators	
	controlling position of masts	raising (lowering) individual masts	discrete control action	is demanding of operator's time
		monitoring position of masts	inspection of indicators	

The reasons for the present assignment of tasks to the two stations and the utilization of up to three operators at the S. and D. station becomes apparent only after an examination of the problems involved in vehicular control of a submarine.

The dynamic response characteristics of the submarine are typified by large mass and by inertia effects which often result in long time delays between an operator's control response and a system response, such as an excursion in depth. For an example, five integrations intervene between movement of the control stick and the resulting depth excursion (stick position $\int$ planes position $\int$ pitch rate $\int$ pitch $\int$ depth rate $\int$ depth). Coupled with the time constants associated with each integration, the task involved in changing depth and, to a lesser extent, maintaining depth, demands a high degree of perceptual skill on the part of the operator(s).

In the same way, course control, seeking and keeping course, requires a high degree of operator skill: (1) because three integrations and their associated time constants intervene between control action and system response (stick position $\int$ rudder position $\int$ turn rate $\int$ course), and (2) because there are strong cross-coupling effects between course and depth maneuvers; changing course can affect depth.

From the foregoing description of the problems involved in controlling the position of the submarine, it is apparent that the most important factors making control difficult are the long time delays between control action taken and system response. Because of these delays, an operator is actually forced to perform mental differentiations and integrations of submarine responses to control perturbations in order to achieve effective control. Further, the long time delays between control action and actual ship displacement virtually eliminates the usefulness of actual displacement as a control cue. While presentation of derived data, for example, pitch rate, does facilitate control to some degree, instantaneous values of these factors cannot provide an operator with the information he needs to determine the time during a maneuver when he should initiate control action or the amount of control action

to take. Additional factors complicating control are the cross-coupling effects on depth from course during a course-seeking maneuver. Under some conditions, a simple course change may affect depth by several hundred feet, if compensating action via the planes is not taken. For these reasons, it is clear why control of depth, pitch, and course using planes and rudder have been assigned to a single station manned by up to three operators, one for each control-activating surface.[9] This arrangement permitted each operator to concentrate on controlling a single parameter and thus reduced the overall vehicular control task to three separate subtasks which were considered manageable. In actual fact, however, these parameters interact and the result of using multiple operators in the loop has been to limit system effectiveness to the ability of any three operators to coordinate their control responses.

As for the tasks assigned to the B.C. operator, only one requires a high degree of skill; this is the task of effecting trim. The task is made difficult because calculation of the amount of trim imbalance is indirect, from information provided by the amount of planes angle used to maintain depth and pitch and/or the rate of change in depth. Further, this estimate must be converted, mentally, into appropriate weight-distance estimates for each of the trim tanks (since the tanks are located at different distances from the center of buoyancy, transferring a given amount of water from or to a particular tank will affect trim differentially). For these reasons the task confronting the operator is a difficult one requiring a high degree of skill.

Only two of the other tasks presently assigned to the B.C. operator can be considered demanding, in that, when performed they are time

[9] The only other task assigned to this station, speed ordering, presents no real demands on an operator either in terms of skill required or time spent on the activity. If speed control were effected directly at this station, however, it would involve extensive monitoring and regulating instruments associated with the propulsion equipment.

consuming. These tasks are: (1) operating the snorkel system and (2) controlling the position of masts. Both involve extensive status monitoring and, although the control responses required are discrete, they are repetitive over relatively short periods of time.

3.3.6 Task Allocation

It was stated earlier that one of the goals of the present study was to specify the requirements for the Ship Control Station which would increase its effectiveness through an optimal utilization of both human and machine capabilities. Through an analysis of present station tasks performed by the human component, it was determined that only certain operator tasks associated with Ship Control were sufficiently complex to require a high degree of skill (perceptual-motor and computational). From the discussion in the preceding section, it was indicated that the factors which make these tasks difficult are the number of integrations with their associated long time constants and the cross-coupling hydrodynamic effects for depth, pitch, and course control and the amount of computation involved in determining appropriate weight-distance measures for trim correction estimated from observed pitch angle and/or depth rate information. In each case, the human operator(s) is required to perform tasks which can be accomplished more effectively (with greater accuracy and speed) by machine components.[10] To increase station effectiveness, these tasks should be assigned to machine components under normal conditions.[11] This would include both the computational aspects and the control responses. By doing this, the need for multi-operator control would be

[10]The present arrangement of subdividing vehicular control tasks and placing several operators in the control loop is not considered optimum, especially for high speed maneuvering, inasmuch as effective multi-operator control requires a high degree of coordination of control responses among operators.

[11]Normal conditions are defined here as those situations in which all relevant equipment is functioning properly.

eliminated and also it would leave the operator free to devote more of his time to monitoring system performance, a task which effectively utilizes the human's superior ability (over machines) to handle unexpected events without previous experience or programming. To accomodate a variety of situations in which operator control is deemed desirable, manual control capabilities also should be provided. Under these circumstances, to facilitate control, display-aiding techniques should be utilized to reduce or eliminate these task aspects (for example, computational) which severely tax an operator's sensory and/or conceptual abilities.

As for the other operator tasks currently associated with Ship Control, all are accomplished effectively by an operator and they can remain assigned to the human component.

3.3.7 Information Requirements

The information requirements presented are those considered necessary for operator control under non-emergency conditions (all subsystems functioning properly); requirements for emergency conditions will be treated separately.[12] In deriving information inputs, the assumption was made that display-aiding techniques are or will be available to facilitate control. The procedure followed for this analysis was to determine information requirements utilizing the same classification, station task-operator task, as shown in Table 3-1. The results of the analysis are presented in Table 3-2.

3.3.7.1 Supplementary Information Requirements

To facilitate control for those situations in which display-aiding is not available (for example, when there is an equipment failure) or when it is not being used (for example, during shipboard training), seven additional items of information are considered necessary.

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[12] For those tasks performed by a machine component under normal conditions, the only information needed by the operator are warning alarms for subsystem failure.

TABLE 3-2

INFORMATION REQUIREMENTS FOR SHIP CONTROL TASKS UNDER NON-EMERGENCY CONDITIONS

Station Task	Operator Task	Info Requirements	Comment
Submerging	ensuring watertight integrity	status of hull openings	is necessary for own ship safety
	flooding MBTs	status of vents	
		indication of tanks flooding	
	planing down	actual speed	
		depth to bottom	is necessary for own ship safety
		ordered pitch angle or rate of ascent	specifies type of down angle to take
		ordered depth	affects submarine response time
		actual depth	
		control director signal*	will reduce task to simple position control
	adjusting NBT	desired water level in NBT	is predetermined weight necessary to achieve neutral buoyancy with the MBT's flooded

*Feedback which incorporates the effects of control action on all terms in dynamic equations affecting depth. As used here a control director signal refers to information supplied by a machine component (computer) which is used to direct an operator's control responses by presenting to him the projected effects on the submarine response of his current control action.

TABLE 3-2 (Cont)

Station Task	Operator Task	Info Requirements	Comment
Submerging (Cont)		sea pressure	to change water level in NBT submerged, pressure in tank has to be approximately equal to sea pressure
		NBT pressure	
		vent status	
		actual NBT water level	
Surfacing	blowing MBTs	indication of tanks emptying	indicates whether on-line air supply is adequate to blow MBT's
		status of air pressure supply	is needed primarily by Command
	planing up	actual speed	
		depth to surface	
		ordered pitch angle or rate of ascent	specified type of up angle to take
		actual depth	
		control director signal	
Depth-Seeking	planing up (down)	actuel speed	
		depth to surface (bottom)	
		ordered pitch angle or rate of ascent (descent)	
		ordered depth	

TABLE 3-2 (Cont)

Station Task	Operator Task	Info Requirements	Comment
Depth-Seeking (Cont)		actual depth	
		control director signal	
Depth-Keeping	holding depth	ordered depth	
		actual depth	
		control director signal	
	holding pitch	ordered pitch angle	
		actual pitch angle	
		control director signal	
	effecting trim	state of trim imbalance	
		actual water levels in trim tanks	
		status of pump(s) pressure	is necessary to ensure pump(s) has sufficient pressure to operate
		control director signal(s) (machine calculated values of appropriate trim tank water levels)	is necessary to relieve operator of computing weight-distance measures
Piloting	adjusting course to avoid obstacles	actual speed	
		location of other ships, land surfaces, etc.	is necessary for own ship safety
		ordered rudder angle	
		ordered course	
		actual course	
		control director signal	

TABLE 3-2 (Cont)

Station Task	Operator Task	Info Requirements	Comment
Course-Seeking	turning ship	actual speed	
		ordered rudder angle	
		ordered course	
		actual course	
		control director signal	
Course-Keeping	holding course	ordered course	
		actual course	
		control director signal	
Speed Ordering	regulating speed	ordered speed	
		order acknowledgment	it is necessary since some time may ensue between receipt of an order and an actual change in ship's speed
		actual speed	
Miscellaneous Tasks			
Energizing Tasks	activating control and indicator systems	status of systems (go-no go)	
		warning alarms	
Regulatory Tasks	maintaining on-line air and hydraulic pressure systems	status of systems	
		standards for systems	
		warning alarms	
	maintaining appropriate internal environment, e.g., hydrogen level	status of parameters (values or levels where appropriate)	
		standards for parameters	
		warning alarms	

TABLE 3-2 (Cont)

Station Task	Operator Task	Info Requirements	Comment
Control Tasks	operatir_ snorkel system	position of snorkel mast	
		status of valves and hull openings	
		status of power	
		warning alarms	
	controlling position of masts	position of masts	
		speed and depth operating limits for masts	

1) Depth rate: in depth-seeking and depth-keeping; in both tasks the value of this parameter must be brought to zero at ordered depth. In addition, it can be used to estimate trim imbalance.

2) Pitch rate: in depth-seeking and depth-keeping; in both tasks the value of this parameter must be brought to zero at ordered depth. In addition, it can be used in lieu of depth rate to estimate trim imbalance.

3) Stern planes position: in depth-seeking and depth-keeping under certain emergency conditions (for example, failure to the stern planes magnetic amplifier).[13] When this occurs, actual planes position is needed to control the ship. In addition, stern planes position can be used to determine the amount of counteracting force being employed to hold pitch and/or depth.

4) Fairwater planes position: under emergency conditions, as above.

5) Turn rate: in course-seeking and, to a lesser extent, in course-keeping; in both tasks the value of this parameter must be brought to zero at ordered course.

6) Roll: Primarily in course-seeking, because snap rolls produce planes and rudder reversal. In addition, steady state roll (list) information is useful in effecting trim.

7) Thermal-salinity levels: in depth-seeking to permit the operator to distinguish between changes in trim caused by internal factors (for example, pumping bilges) and those caused by external factors (changes in the thermal-salinity condition of the immediate environment).

[13] Failure to a magnetic amplifier for any of the control activating surfaces, stern planes, fairwater planes or rudder, will change the nature of the task from position control via the control stick to rate control.

3.3.8 Specifications for a Ship Control Station

From the analyses performed in the preceding sections, the following conclusions are drawn with regard to the requirements for a ship control station:

1) A unified Ship Control Station is preferable to the present arrangement of two separate stations: the Steering and Diving (S. and D.) Station and the Ballast Control (B.C.) Station. The assignment of different aspects of the depth control function to two separate stations is not considered optimal because, as was pointed out earlier, effective control of this parameter may require planes manipulation, water transfer, or some combination of both. Coordinated control over the same parameter (depth) across two stations is subject to the same disadvantage inherent in multi-operator control of a single parameter, that is, effectiveness is limited by the ability of the operators to coordinate their control responses. Another reason why this arrangement is less efficient than a single station is that the information needed to control depth using either method is, to a large extent, identical (for example, pitch, depth rate, and actual depth). This results in an extensive duplication of instruments which would be eliminated by unification.

2) It is unnecessary to have all the tasks currently performed at the B.C. station accomplished at Ship Control. Virtually all of the miscellaneous tasks, energizing, regulatory and control, presently performed at the B.C. station, are not directly related to the three functions considered to constitute the responsibility of Ship Control. For this reason, these tasks can be assigned elsewhere without reducing the effectiveness of the Ship Control Station and the tasks assigned to Ship Control can be limited to those directly related to the station mission (control of the spatial attitude, spatial orientation, and velocity of the vessel).

3) Automatic control and display-aiding techniques should be provided for trim correction as well as course and depth seeking and keeping.

As was pointed out earlier, machines can accomplish the computational aspects of these tasks more effectively than the human operator and the assignment of these tasks aspects to machines will eliminate the need for multi-operator control.

The above conclusions have been used as guidelines in accomplishing the second objective of this study: the design of a Ship Control Station Console for the FY'65 attack class submarine.

3.4 FY'65 SHIP CONTROL CONSOLE DESCRIPTION

3.4.1 General

The FY'65 Ship Control Console described here is based on: (1) the analyses performed in the preceding section, (2) the conclusions drawn from these analyses, and (3) considerations with regard to redundancy back-up systems.

3.4.2 Design Philosophy

The Ship Control Station Console described below is designed for one man control, under normal watchstanding conditions, of the major functions formerly associated with the Steering and Diving Station and the Ballast Control Station. Provision is made also for an emergency helmsman's station at the console in the event of a subsystem malfunction which necessitates the use of an additional operator or for those situations for which dual control is deemed desirable.

In designing the console, two basic decisions were made: (1) to limit, for the most part, the functions accomplished at this station to those involved in controlling the spatial attitude, spatial orientation, and velocity of the ship and (2) to assign virtually all miscellaneous tasks to another station, the "monitoring" station.

Within the guidelines adopted, the following tasks were delegated to the Ship Control Station:

1) Steering and Diving (course and depth control using planes and rudder).

2) Ballast and Trim (depth control using water transfer).

3) Speed Ordering.

4) Miscellaneous Tasks: responsibility for monitoring and regulating certain critical indications of own ship safety related to ship control operations. These include:

a) monitoring watertight integrity.

b) monitoring and regulating the operation of the snorkel system.

c) monitoring and regulating the raising and lowering of masts.[14]

3.4.3 Console Design

3.4.3.1 Physical Description

The Ship Control Console is shown in Fig. 3-1. The console dimensions, including the wing extension angled 45° from the left side of the front portion are presented in Fig. 3-2. Figs. 3-3, 3-4, and 3-5 are provided to facilitate an evaluation of anthropometric considerations. Fig. 3-3 is a cross section view, Fig. 3-4 shows the viewing angles and Fig. 3-5 shows the reach distances to the various panels on the console.

The design of the console (size, shape, and inclination of panels) is such that a seated operator 5'9" in height (50th percentile man) is always within effective viewing distance of all the displays. Further, all controls are placed well within effective reach distance and the seated operator with shoulders fixed will be able to reach all controls.

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[14] The degree of involvement by the ship control operator with these functions is discussed in subsequent sections.

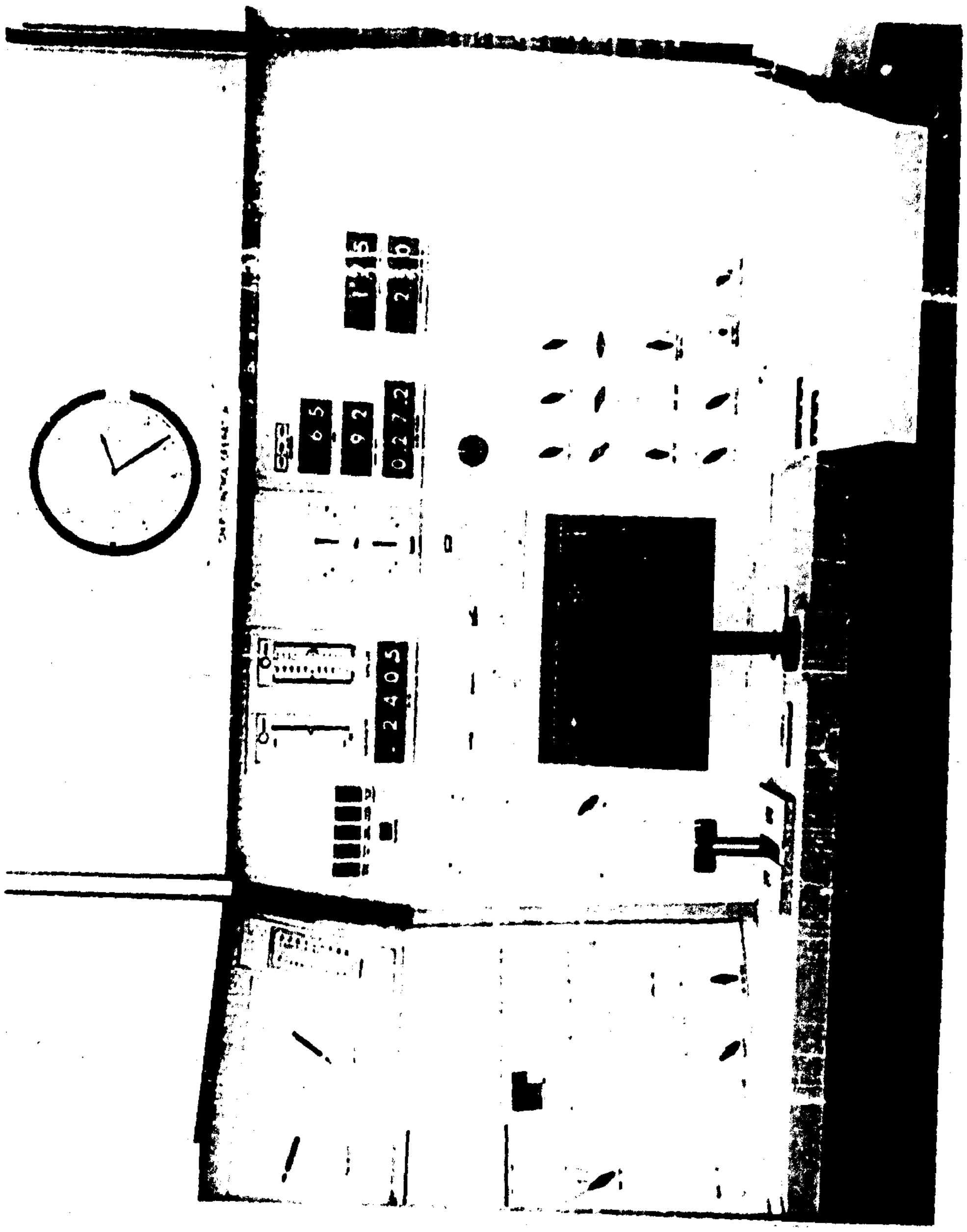

FIGURE 3-1 SHIP CONTROL CONSOLE

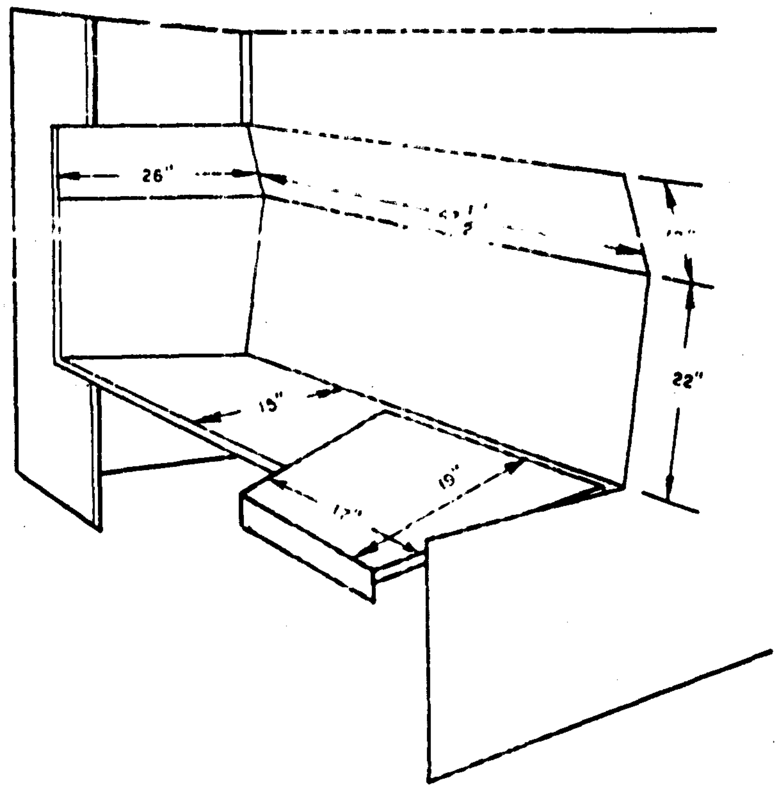

FIG. 3-2 SHIP CONTROL CONSOLE DIMENSIONS

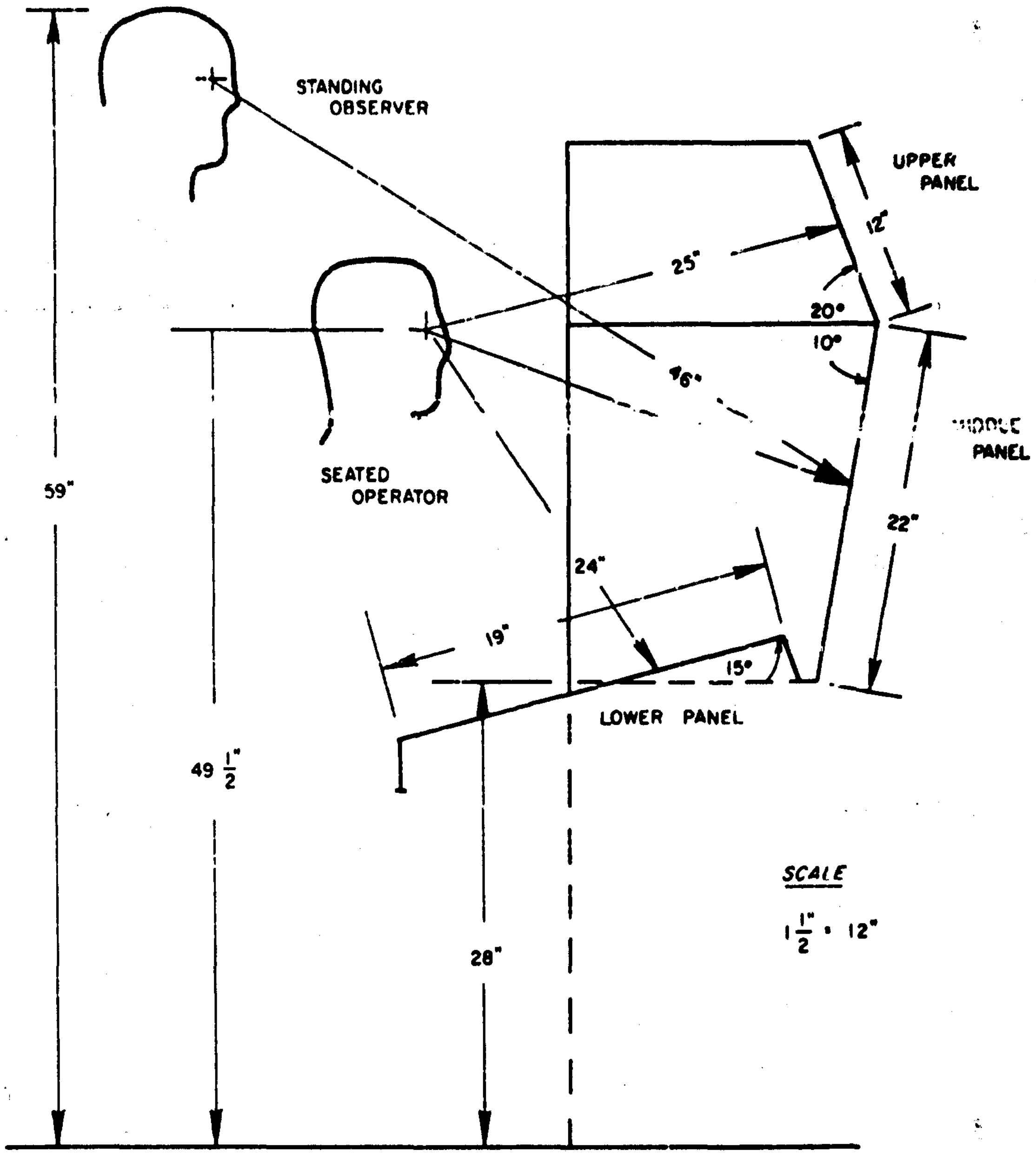

FIG. 3-3 CROSS SECTION OF SHIP CONTROL CONSOLE

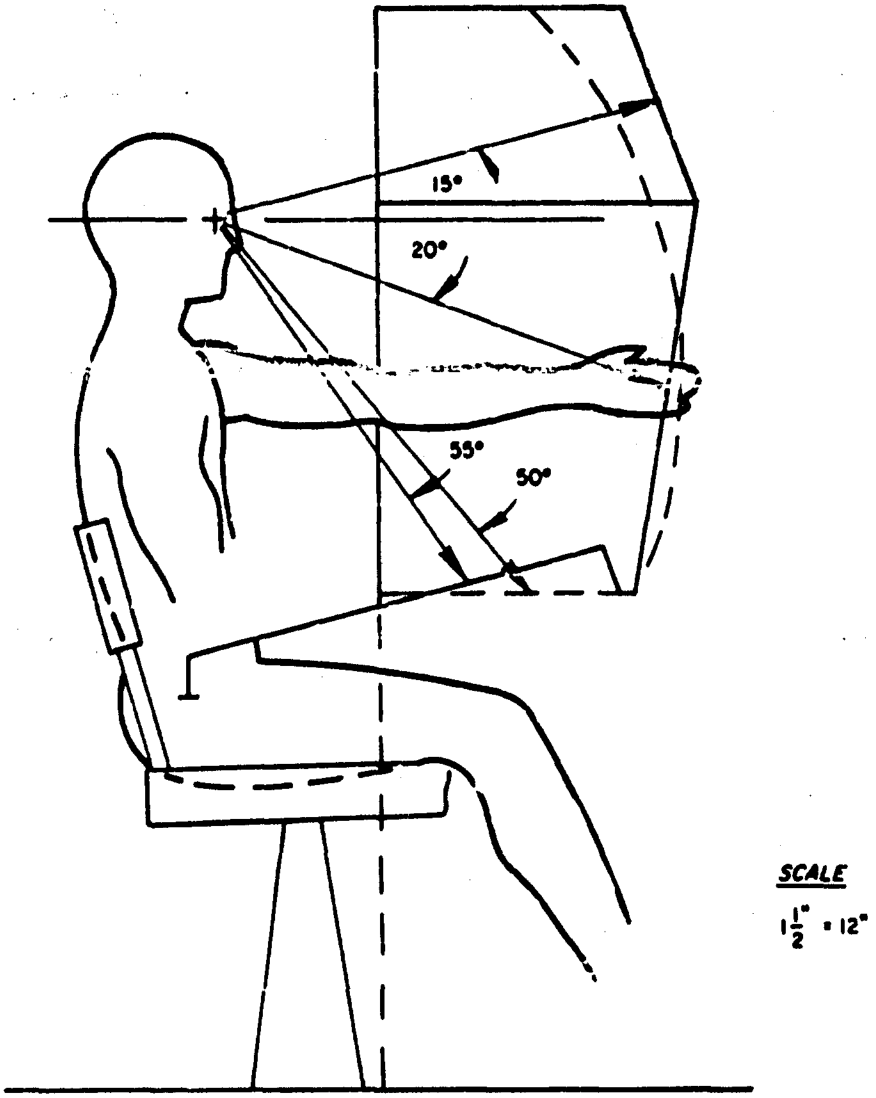

FIG. 3-4 VIEWING ANGLES TO SHIP CONTROL CONSOLE

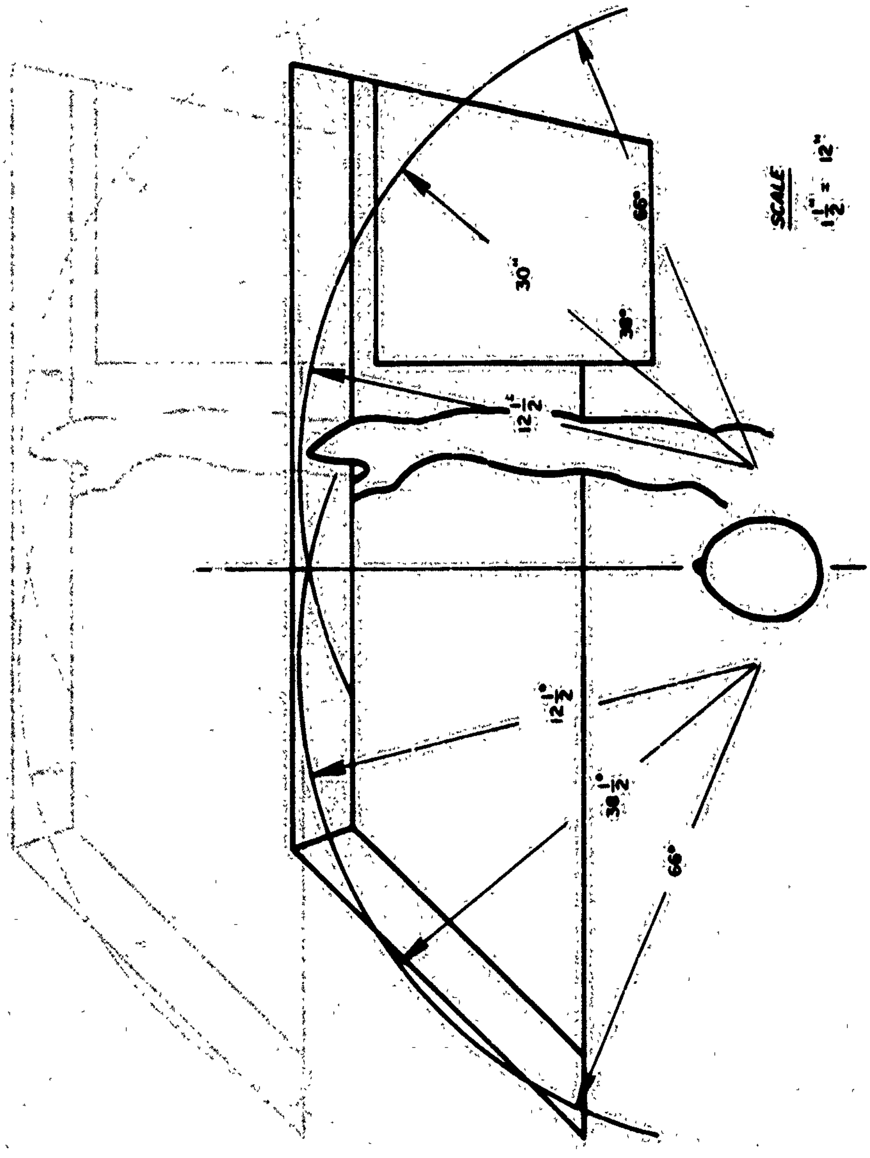

FIG. 3-5 REACH DISTANCES TO SHIP CONTROL CONSOLE

except for one, by extending his arm(s). To reach the one exception, an infrequently-used control placed on the upper panel to maintain spatial contiguity with its associated displays, the operator will have to extend his shoulders slightly. To accomodate the variability in operators expected to use the console, the adjustable seat range (up-down, forward-back) will encompass the 5th through the 95th percentile of service personnel.

3.4.3.2 Functional Description[15]

Under normal conditions, the ship control operator will serve as an effector link between command and the machine components and, as such, he will execute orders issued by command (or a command surrogate) for controlling depth and course and also relay orders for changing speed. Since he will be the person effecting changes in these parameters, it is necessary to provide at his station certain information related to own ship safety. This information can be used by command, if time permits, or by the operator himself to initiate action, when required, to ensure the safety of the ship. For this reason, certain indicators are present on this console solely to permit initiation of action by the ship control operator in emergency situations, that is, those situations in which the safety of own ship may be jeopardized if immediate corrective action is not taken (these instruments will be discussed under 3.4.4.4 Miscellaneous Tasks).

To facilitate one man control, automatic control and display-aiding techniques have been provided for the two most demanding functions performed at ship control: (1) steering and diving and (2) trim control.[16] In addition, a separate capability for controlling depth at zero speed has been provided.

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[15]For the description which follows, reference is made to Fig. 3-1

[16]For the remaining tasks, ballast and speed ordering, no radical changes in control techniques (other than instrumentation) have been incorporated inasmuch as both these functions are considered non-demanding of either the operator's time or skill.

3.4.4 Ship Control Tasks

3.4.4.1 Steering and Diving

3.4.4.1.1 Modes of operation - Control of depth and course using planes and rudder can be accomplished using any one of three modes of operation.

1) Primary: completely automatic control of depth and course, singly or in combination; control of the other parameter would be manual in the former case.

2) Secondary: manual control of depth and course, singly or in combination by a single operator; control of the other parameter would be automatic in the former case.

3) Tertiary: manual control of depth and course by two operators; the ship control operator controlling the planes (depth) and an emergency helmsman controlling the rudder (course).

Any one of the three control modes can be used under normal conditions; for casualty conditions, four such situations can be specified.

1) Failure to a hydraulic power system: the loss of the main hydraulic system would not require more than a single operator at the station. The vital and lead hydraulic systems have equal capacity to the main and substitution of anyone for the other would not decrease control effectiveness.

2) Failure to the automatic control system: failure to the automatic control system for course or depth would require a change in control modes; but, here again, a single operator would suffice as long as no failure occurred in the display-aiding mechanism.

3) Failure in one or more of the magnetic amplifiers: loss of electrical power to one or more of the hydraulic valves (magnetic amplifier failure) would require a change in control modes. At this time, an "emergency power" condition would prevail. Control would change from a position control closed-loop servo system to

a rate servo system with the operator directly controlling the rate of flow of oil through the hydraulic valve(s). Dual control (tertiary Mode) would be advisable here to minimize the likelihood of confusion errors as a result of changing from position control to rate control.

4) Failure of a hydraulic valve or loss of electrical power to one of the hydraulic rams: casualty of this kind would require the use of additional personnel. Emergency control for this situation cannot now be exercised at ship control, but it is exercised at the location of the casualty or via hand pumps in the control room. This method of operation will be maintained.

The major reason for providing the dual operator mode (Tertiary) is to facilitate control when a failure occurs to the principal ship control display or when a power failure occurs which necessitates the use of mechanical indicators for depth and course.

3.4.4.1.2 Displays (See Fig. 3-6 thru 3-8) - Three separate display systems are provided for presenting depth and course information.

1) SQUIRE (Submarine QUIckened REsponse) display: this is the principal ship control display. Through the use of quickening, it affords position control of depth and course by the operator(s) in Secondary or Tertiary and also serves as a monitoring display while under automatic control. It consists of a 17-inch CRT with grid overlays and scales for depth and course located on the four edges of the display.

For all conditions of operation, three symbols are presented continuously: (1) an ordered depth and course symbol (rectangle), variable in size, with tick marks variable in number and spacing on all four sides; (2) a quickened depth and course symbol (dot), variable in size; and (3) an actual depth and course symbol (cross), variable in size.

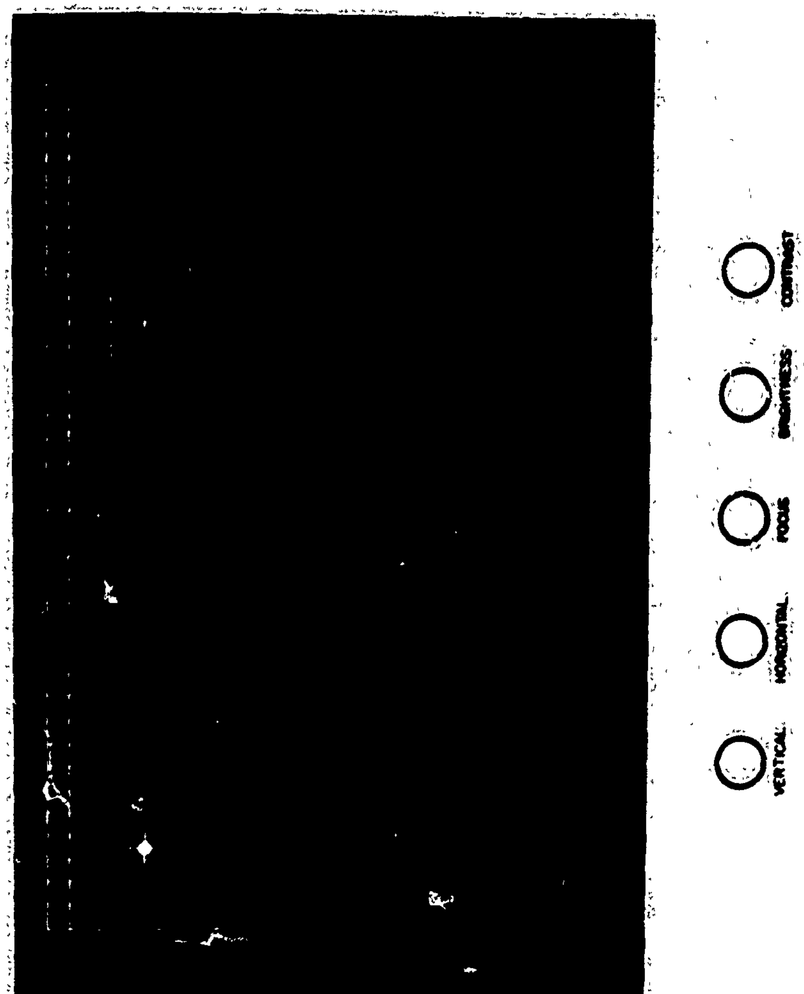

FIGURE 3-6 SQUIRE

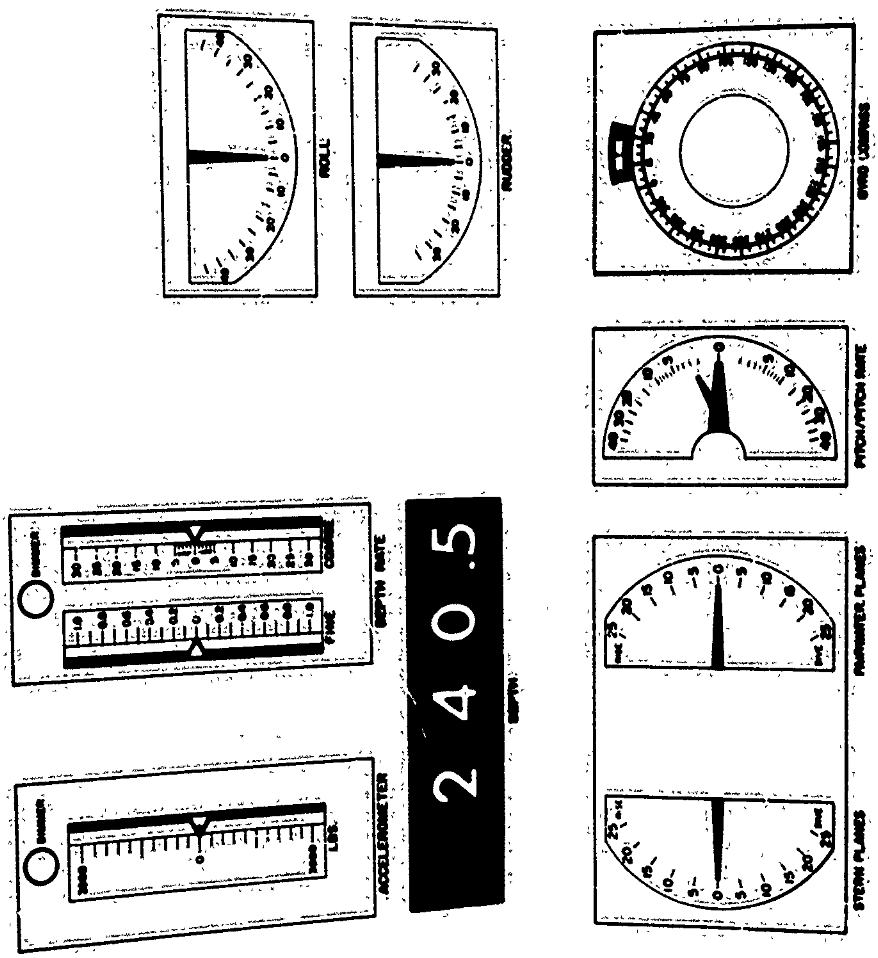

FIGURE 3-7 AUXILIARY DISPLAYS FOR STEERING AND DIVING

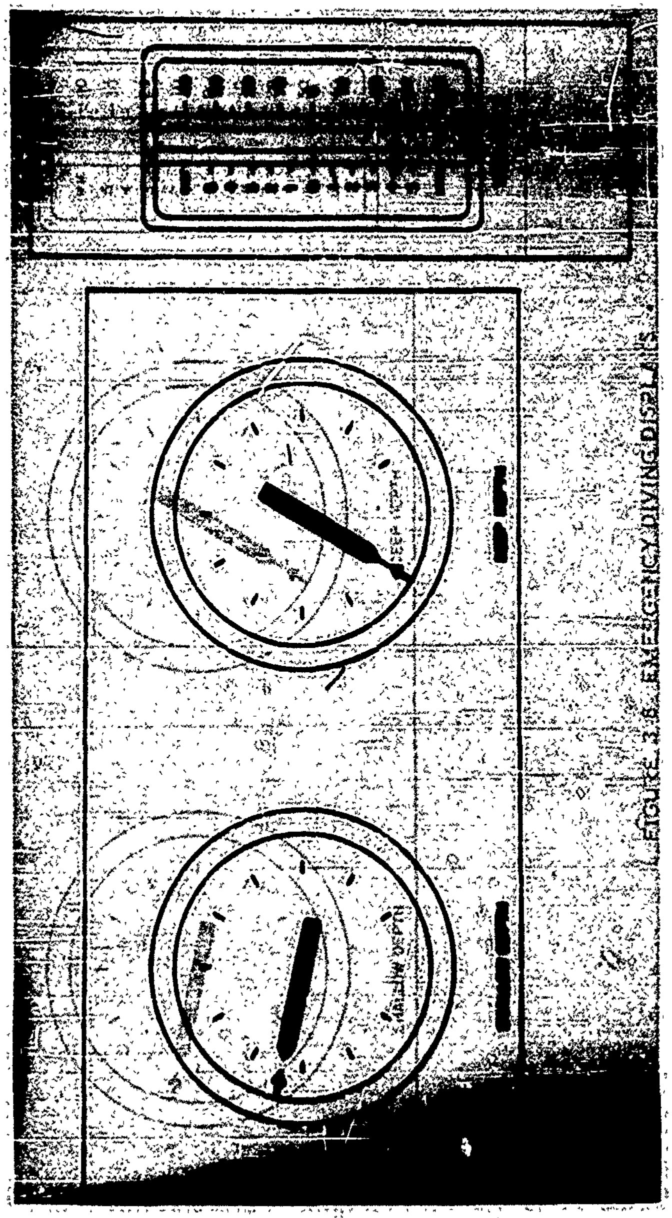

FIGURE 3-8 EMERGENCY DIVING DISPLAYS

TV periscope, Radar and Sonar information also can be displayed. When SQUIRE is used to present any one of these sources of information, the presentation will be superimposed over the SQUIRE symbols. Other information depicting depth to surface and depth to bottom also are presented on the display, these being continuously available.

The SQUIRE display can be used while operating in any one of the three control modes.

2) Auxiliary Displays (electro-mechanical): in the event of a failure to SQUIRE, quickening is no longer available for depth and course control. To obtain depth and course information in this situation, auxiliary indicators are provided; these also can be used for proficiency maintenance and shipboard training. The eight displays constituting the auxiliary indicators for steering and diving are:

a) digital depth indicator

b) depth rate indicator[17]

c) combined pitch - pitch rate indicator

d) stern planes indicator

e) fairwater planes indicator

f) rudder angle indicator

g) gyro course repeater

h) roll-list indicator

[17] Depth rate can be estimated fairly accurately by experienced operators from a digital depth indicator. The reasons for displaying depth rate separately are that it is useful in determining trim imbalance and also so that orders given in rate of descent (ascent) can be effected accurately. On the other hand, turn rate is not displayed because it can be estimated fairly accurately from course information and it is only used in changing course.

Since a failure to SQUIRE does not necessarily involve a failure in the automatic control system, all three control modes can be employed with the auxiliary instruments.

3) Emergency Indicators (mechanical): a separate group of mechanical indicators are provided for full emergency back-up in the event of a general power failure which causes the loss of electronic indicators. The following instruments are provided for emergency depth control:

a) shallow depth gauge

b) deep depth gauge

c) trim "bubble" gauge

Considering the conditions that would prevail when these instruments are being used, it was assumed that dual operator control of depth and course (Tertiary mode) is preferable; the location of these instruments on the console reflect this assumption.

3.4.4.1.3 Controls (See Figures 3-9, 3-10 and 3-11) - The following controls are provided for steering and diving.

1) Steering Mode Selector: this control is used to select the mode of operation for course control. In Primary rudder control is effected via the computer, in Secondary via a joystick, and in Tertiary via an emergency helm (wheel).

2) Diving Mode Selector: this control is used to select the mode of operation for depth control. In Primary both fairwater and stern planes are controlled via the computer, in Secondary and Tertiary control is exercised via a joystick.

3) Gain Mode Selector: this control is used to adjust the dimensions of the three symbols for depth and course presented on SQUIRE to obtain varying degrees of precision. It can be used in all three control modes as long as SQUIRE is functioning.

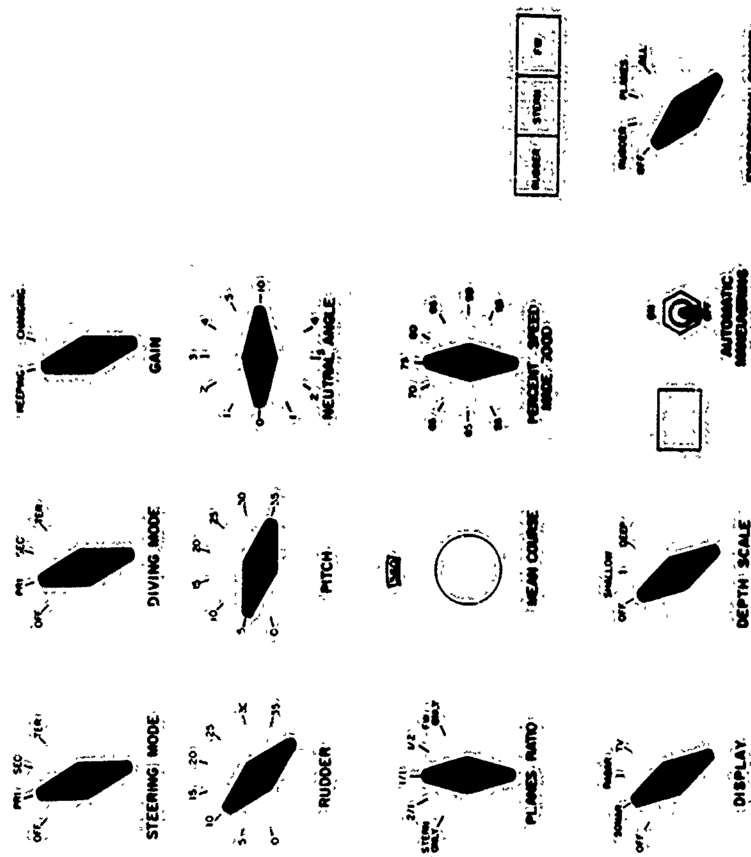

FIGURE 3-9 SELECTOR CONTROLS FOR STEERING AND DIVING

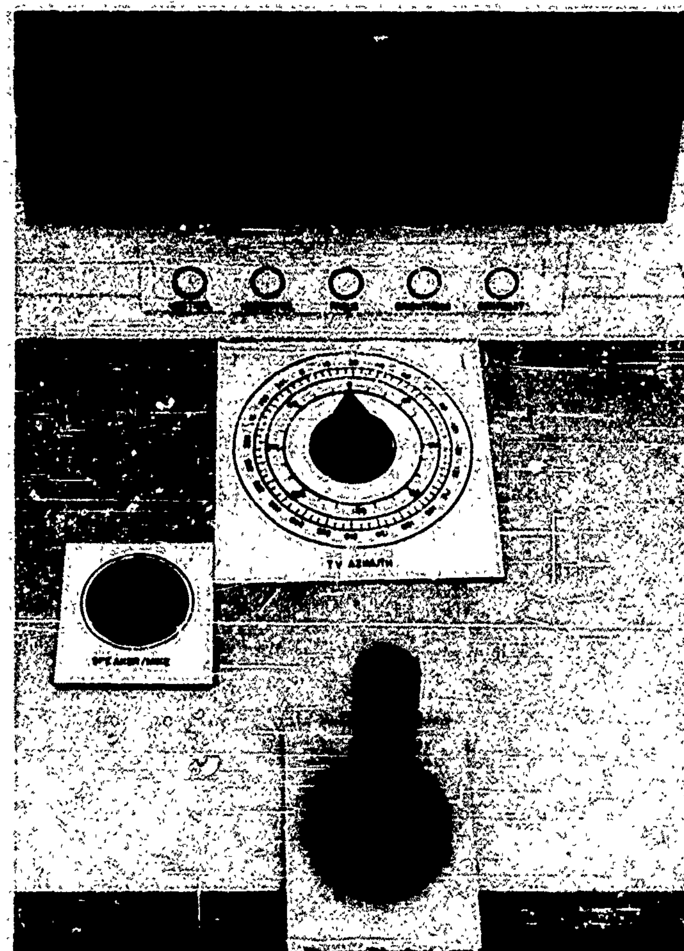

FIGURE 3-10 JOYSTICK CONTROL, TV AZIMUTH SELECTOR, AND SPEAKER MIKE

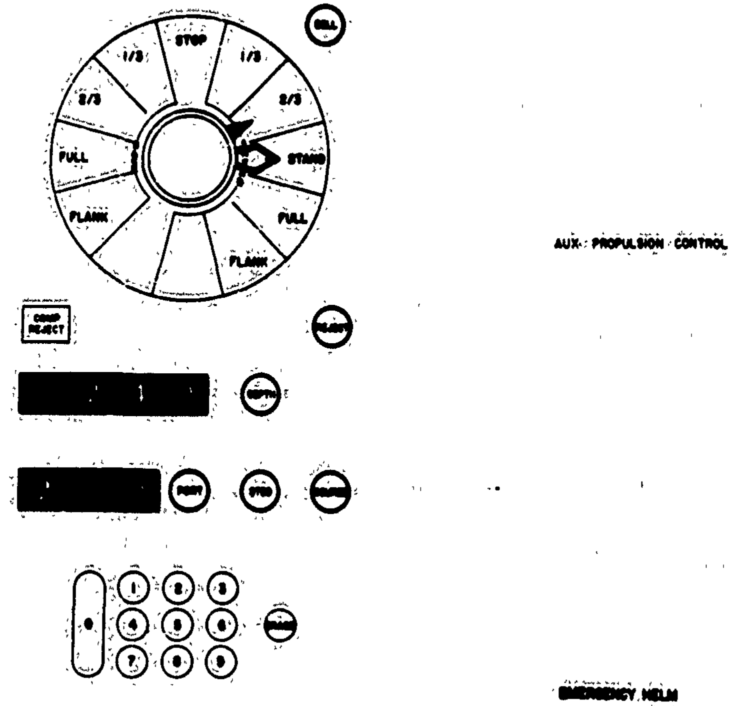

FIGURE 3-11 ANNUNCIATOR, COMPUTER KEYBOARD, AUXILIARY PROPULSION SYSTEM, AND EMERGENCY HELM

4) Maximum Rudder Limiter Selector: this control is used to provide maximum rudder angles for changing course. In Primary the setting selected will limit the turn rate, in Secondary or Tertiary the selected value will limit the rate of movement of the quickened symbol and, thus, indirectly limit manual turning rates.

5) Maximum Pitch Limiter Selector: this control is used to provide maximum pitch angles for changing depth. In Primary the selected value will limit the maximum pitch angle utilized by the computer, in Secondary or Tertiary the selected value controls the rate of movement of the quickened symbol and, thus, indirectly limits the pitch angle utilized.

6) Neutral Angle Selector: this control is used to provide steady state pitch angles. In Primary the setting selected will determine the angle on the ship held at ordered depth and also control the quickened symbol on SQUIRE such that it shows no depth excursion for non-zero pitch. In Secondary and Tertiary only the quickened symbol is controlled; however, the desired pitch angle can be maintained with this symbol, since it will show as a depth excursion any deviation from the pitch angle selected.

7) Fairwater/Stern Planes Ratio Selector: this control is used to select a planes ratio in all three modes.

8) SQUIRE Display Mode Selector: this control is used to select the presentation desired (sonar, TV, or radar) discussed previously under SQUIRE.

9) Depth Scale Selector: this control is used to change depth scales for SQUIRE. Two scales are available, shallow or deep, and the change made results in the appearance or disappearance of a third digit (units place).

10) Mean Course Selector: This control is part of the automatic maneuvering system as are the two controls. It is used to designate to the computer the mean course (track) for own ship.

11) Percent Speed Made Good Selector: this control is used to designate to the computer the percentages of actual speed to make good.

12) Automatic Maneuvering Control: Once a mean course and percentage of speed to make good are selected, positioning this control to the "on position" will command the computer to generate a random track which satisfies these two conditions as well as any other limits which are placed on maneuvering, e.g., minimum and maximum zig angles, minimum and maximum times on a given heading. The system can be used in all three control modes. In Primary, all changes in course will be accomplished automatically. In Secondary or Tertiary the computer will drive the ordered symbol and the operator will track the ordered symbol with the quickened symbol.

13) SQUIRE Tuning Controls: these controls are used for adjusting the vertical gain, horizontal gain, intensity, focus, or brightness of SQUIRE.

14) TV Azimuth Selector: this control is used when the SQUIRE display is presenting TV information. It is used to control the azimuth of the TV camera and permits the determination of relative or true azimuth.

15) Computer Entry Keyboard: this instrument is used to enter orders for course and depth changes to the computer. It consists of a standard keyboard, pushbuttons for depth, and course and digital readouts for each of the ordered parameters. Since the computer will take the shortest path to effect a course change, special order controls, "come left" and "come right", are provided. An indicator is provided to show that an impossible order has been given and a computer reject control to countermand a previous order. In Primary all symbols on SQUIRE will be driven via the computer. In Secondary or Tertiary the keyboard is used to position the ordered symbol only.

16) Joystick Control: this control is used by the operator to control depth and course in Secondary and depth in Tertiary. With SQUIRE operating, control director information is provided by the position of the ordered symbol and the movement of the quickened symbol. In the absence of SQUIRE, either the auxiliary displays or the emergency indicators are used to control depth and course. Two switches are mounted on the joystick, an override switch and an order switch. The override switch enables the operator to bypass the computer. Its unique function is to allow immediate manual control without using the mode selectors. The order switch enables the operator to position the ordered symbol without using the keyboard. Here again, it permits immediate action to be taken.

17) Magnetic Amplifier Failure Alarms and Emergency Power Selector Control: three indicators (red-green lights) for each of the control surface amplifiers (fairwater planes, stern planes, and rudder) are provided. Green signifies the amplifiers are functioning properly; red indicates a failure. To direct the operator's attention to an amplifier failure, the corresponding indicator will change from green to red and begin to pulsate until corrective action is taken, that is, switching to emergency power. This will occur in conjunction with the release of an audible alarm. When corrective action is taken, the amplifier indicator ceases to pulsate but remains red until the amplifier is working properly. The selector control provided is a four position rotary switch. Positions are: (1) off, (2) rudder, (3) planes, and (4) all. Although it may be desirable for effective control to change modes, specially to change to Tertiary, the two systems are independent of each other in terms of function.

18) Auxiliary Propulsion Unit: this control is used in the event of a failure to the main propulsion system.

19) Emergency Helm: this control is a wheel which is used by a second operator to control the rudder. The Steering Mode Selector must be set at Tertiary for the wheel to be activated. At that

time, the rudder is freed from control by the computer or by the joystick depending upon the mode of operation in effect prior to the mode change.

3.4.4.2 Ballast and Trim Control (See Figures 3-12, 3-13, and 3-14) Four separate systems for controlling depth using water transfer are provided.[18]

3.4.4.2.1 Main Ballast Tanks System - This system is used to rapidly effect the gross changes in weight overall required for submerging or surfacing. The instruments provided are:

1) dual lever-in-groove controls for venting, flooding and blowing, singly or in combination, the forward and after main ballast tank groups.

2) vent, flood, and blow indicators located adjacent to the controls.

3) two color light (red-green) signifying the condition of the on-line air supply connected to the high pressure blower system. Red indicates an insufficient supply of air necessitating changing air banks; green indicates that an adequate air supply is available. Monitoring and regulating the air supply is not accomplished at ship control but at the Maintenance Monitoring Station.

3.4.4.2.2 Special Ballast System (Negative Buoyancy Tank) - This system is used to attain an initial condition of neutral buoyancy when first submerging. Water can be transferred from this tank by flooding and blowing for gross changes in water level and through the trim pump system for fine changes. The instruments provided are:

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[18] Three of these (1) the Main Ballast Tanks System, (2) the Special Ballast System (NBT), and (3) the Variable Ballast System (Trim tanks) are maintained from previous vessels, although design changes in displays and controls and the incorporation of display-aiding and automatic control for trim are reflected in the instruments provided. The fourth system, for hovering and changing depth at zero speed, utilizes part of the Variable Ballast System, but when used it provides a separate capability for depth control.

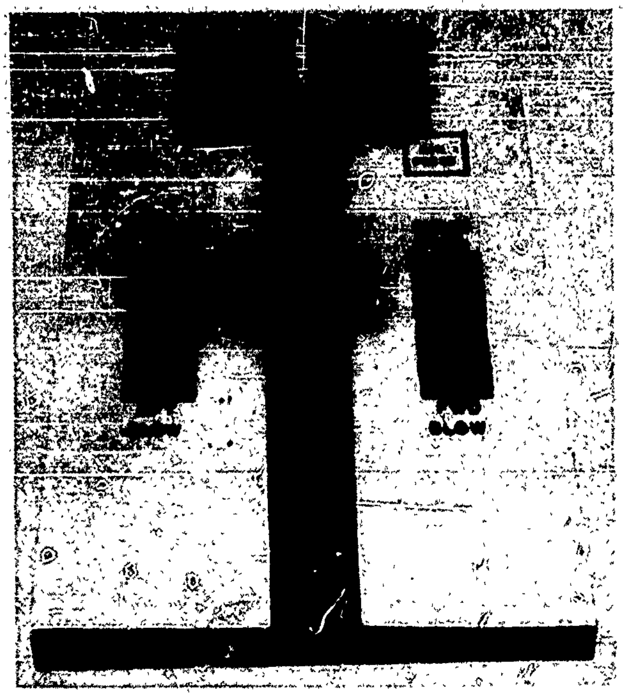

FIGURE 3-12. MBT SYSTEM

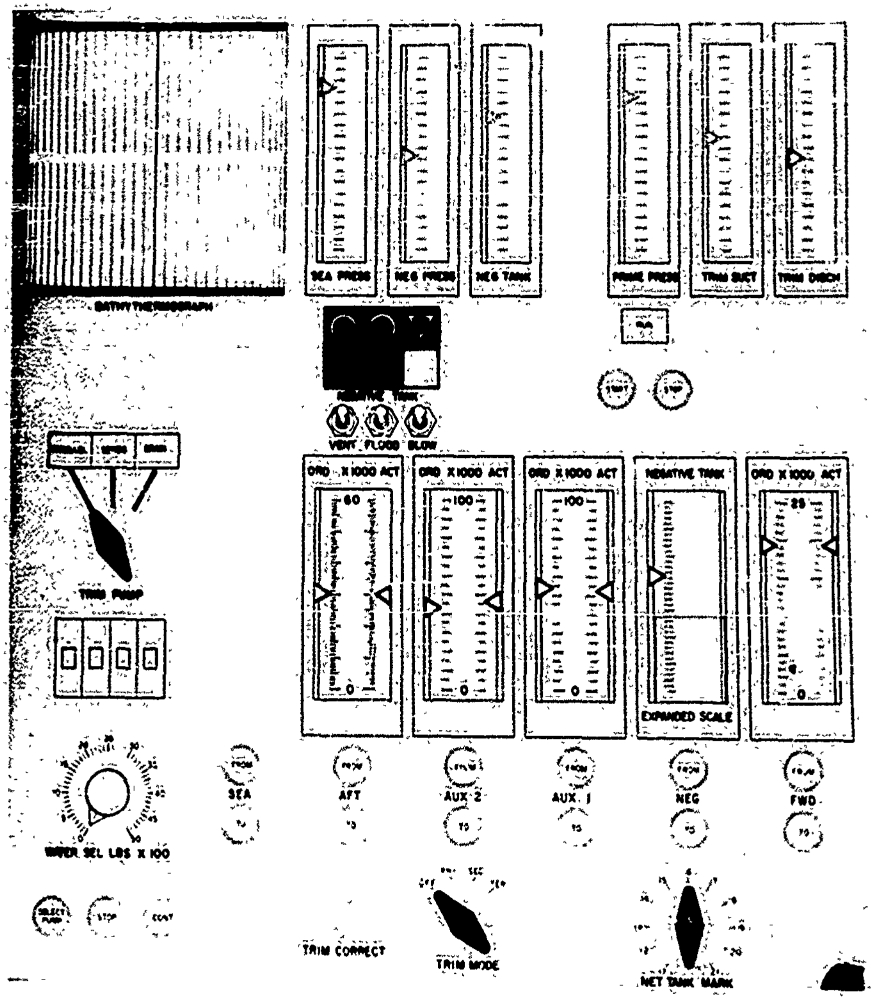

FIGURE 3-13 SPECIAL AND VARIABLE BALLAST SYSTEMS

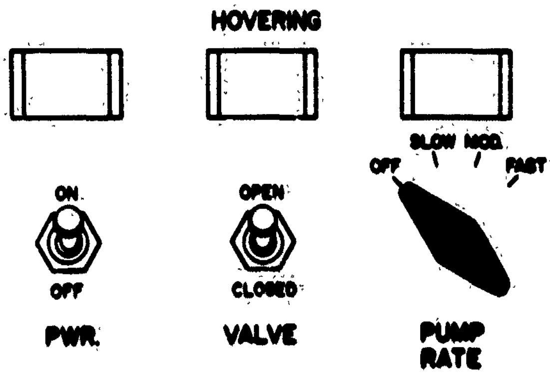

FIGURE 3-14 ADDITIONAL HOVERING SYSTEM INSTRUMENTS

1) displays and controls for venting, flooding, and blowing the negative tank. Aside from indicators for sea pressure and actual negative tank pressure, the full scale negative tank water level indicator is located here rather than with the trim tank level indicators. This is done to facilitate blowing and flooding operations.

2) expanded portion of negative tank water level indicator scaled about the neutral buoyancy "mark," and "mark" selector control. Since blowing and flooding are gross operations, fine control of negative tank water level is best accomplished using the trim pump. For this reason, an expanded portion of the full scale tank indicator is located among the trim tank indicators. The pointer will register at some preset level below the level predetermined to yield neutral buoyancy for the operating depth ("mark") (for example, 1000 lbs) and will continue to register up to an equal amount past the "mark." If the level of water is less than or greater than the preset limits, the indicator will not register. When this occurs, the continuation of blowing or flooding is indicated. To permit the use of this indicator over a wide range of predetermined values for neutral buoyancy, a selector control is provided. The operator sets some value (for example, 12000 lbs) which sets the range of this scale for 11000 to 13000 lbs.

3.4.4.2.3 Variable Ballast System (Trim Tanks) - This system is used to effect fine adjustment in trim (fore, aft, or amidships balance and weight overall). Three modes of operation for this system are provided.

1) Primary: automatic calculation and correction of trim imbalance as it occurs.

2) Secondary: automatic calculation and correction of trim imbalance effected by operator order. Regardless of the degree of trim imbalance, no correction will be made unless the operator directs the computer to do so via an order control.

3) Tertiary: in this mode, the operator must correct trim imbalance. If the computer is functioning, desired levels for the

trim tanks will be calculated, but the operator must manually activate the pump system and direct the flow of water being moved.

The instruments provided for this system are:

1) trim tank indicators: four indicators for the forward, auxiliary (1 & 2), and after trim tanks are grouped with the negative tank indicator (expanded scale) described previousl· Except for the negative tank indicator, all trim tank indicat· s have two pointers. One of these is driven by the computer and shows the calculated level of water appropriate to the tank; the other pointer registers the actual level of water in the tank. In addition, a red overlay also driven by the computer will show criticality of trim correction. In Primary and Secondary these displays are monitored by the operator. In Tertiary with the computer functioning, calculation of trim imbalance is simply a matter of subtracting the calculated value from the actual value or vice versa. With a computer failure, the final value calculated will still register and should prove helpful in correcting trim imbalance. If not, the operator must use pitch, planes position, and/or depth rate information to effect trim (the procedure currently used).

2) bathythermograph (temperature-salinity recorder). This instrument will continuously record changes in the temperature-salinity condition of the water on a scale calibrated in pounds to reflect these changes in weight overall. The instrument is provided to facilitate trim correction in the event of a failure to the computer (Tertiary mode).

3) pump pressure indicators showing pressure in the prime pump and suction and discharge sides of the trim pump. Controls for operating the prime pump and a "run" light also are provided. The trim pump pressure indicators are located at ship control rather than at the Maintenance Monitoring Console, because the pressure necessary to operate the pump at any given instant can vary over a wide enough range to warrant their inclusion here. The

sufficient reason for including the prime pressure indicator is to ensure that this pump is not damaged due to its use below the pressure required for its safe operation.

4) trim mode selector: used to select the mode of operation for the trim system.

5) trim correct button: used to order the computer to correct trim while operating in the Secondary mode.

6) six sets of "From-To" controls for pumping water from and to the several trim tanks (including the negative tank) and the sea. Except for the connection of the negative tank and sea, controls are not activated unless the mode of operation is Tertiary.

7) trim pump selector and indicators. This control permits the operator in Tertiary to select the condition of operation for the trim pump (parallel or series) and also to connect the drain pump to the trim tanks, if the trim pump should fail.

8) water selector control and flow meter. The control permits the operator to select, in advance, the amount of water to be moved. It is used only in the Tertiary mode. The flow meter is used for monitoring water transfer.

9) trim pump controls and "run" light, all used in Tertiary. There are three controls: a selector pump control used in conjunction with the water selector, a continuous pump control used when no setting is made on the water selector, and a stop control used with the continuous control.

3.4.4.2.4 Hovering System - This system is used to control depth at zero speed and also to control the rate of ascent or descent while stopped using water transfer. The system will operate using the auxiliary trim tanks operated in combination via separate pump system capable of varied flow rates. Two modes of operation are possible for either holding depth or changing depth.

1) Primary: completely automatic when the diving mode selector is set at Primary.

2) Secondary: manual control when the diving mode selector is set at Secondary.

The instruments provided for this system are:

1) hovering control and indicator. When activated the control will change the quickening equations for depth to increase the sensitivity of the display around the ordered depth. In addition, it opens the valve connections from the auxiliary tanks, in combination, to the hovering pump system and operates the pump in Primary. The indicator, when lit, signifies that the hovering system is functioning properly. In Secondary the control only changes the quickening equations.

2) valve control and indicator. In Secondary the valves must be opened manually; the indicator will light in either mode for "valves open."

3) pump control and indicator. In Secondary this control is used to select a pumping rate. In Primary the computer will utilize the setting made. Again the indicator will light in either mode.

4) keyboard entry control. To hold depth in either mode the computer will use the previously entered value for depth. To change depth a new ordered depth must be entered; this will position the ordered symbol on SQUIRE. In Secondary the keyboard can be by-passed; the quickened symbol is driven without regard to the position of the ordered symbol.

5) joystick control. In Secondary the joystick is used to maintain or change depth, in conjunction with the SQUIRE or using auxiliary instruments, by pumping water in or out of the tanks. As envisioned the planes will remain coupled and some movement will occur. At zero speed, however, the effect of this movement will be slight or non-existent.

6) SQUIRE: used for monitoring in Primary and for directing pumping action in Secondary.

7) digital depth indicator. This instrument is used if SQUIRE fails. In addition, to facilitate control without SQUIRE two other instruments are provided. These are:

8) depth rate indicator. This display is separate from the depth rate indicator described under auxiliary instruments. It is calibrated in tenths of a foot and is used in hovering and changing depth at zero speed.

9) accelerometer. This instrument is scaled in pounds to plus or minus 3000 lbs. It is used in conjunction with the fine scale depth rate indicator.

3.4.4.3 Speed Ordering (Figure 3-14)
The instruments provided for this task are:

1) speed ordering annunciator. This is a dual pointer indicator and control with one pointer being positioned by turning the control (rotary dial) while the other pointer is positioned via a signal from the station actually effecting speed changes.

2) digital speed indicator in knots.

3.4.4.4 Miscellaneous Tasks (Figure 3-15)
Instruments are provided for the following tasks:

1) Monitoring watertight integrity: five standard circle-bar indicators plus a red-green rig-for-dive light are provided for this function. The five indicators show the status of the following hull openings:

a) bridge hatch
b) outboard induction
c) main snorkel
d) engine exhaust
e) outboard vent exhaust

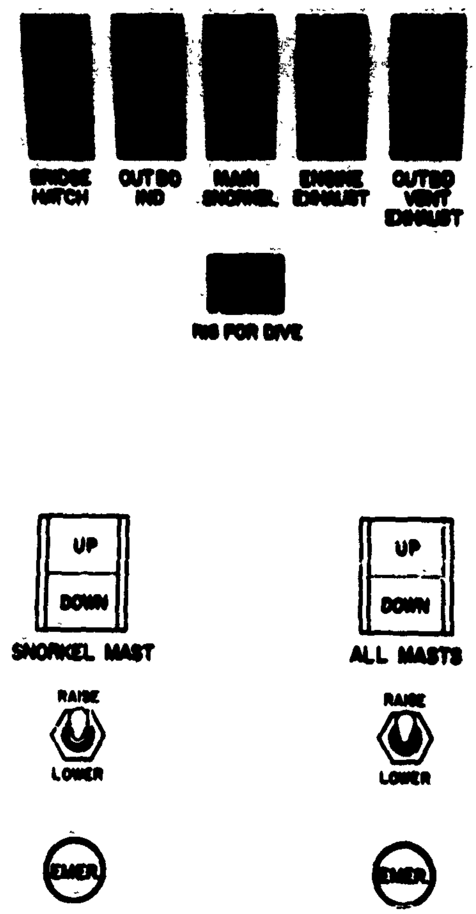

FIGURE 3-15 RIG-FOR-DIVE INDICATORS, SNORKEL AND MAST ORDER CONTROLS

2) Monitoring and Regulating the Operation of the Snorkel System. Physical controls for operating the snorkel system will not be provided at Ship Control. To ensure the safety of the ship, snorkel operations will be ordered via Ship Control or permission will be obtained from Command and communicated to the operating station via Ship Control. To permit an override function to be effected at Ship Control, the following instruments are provided:

a) summary indicators for the snorkel mast. There are two positions, mast up, and mast down.

b) an order control used to order the start of the snorkel operation and also to order its cessation.

c) an emergency shutdown control used to shut down the system completely and to close all snorkel hull openings.

3) Monitoring and Regulating Mast Position. Physical controls for raising and lowering masts will not be provided at Ship Control. To ensure the safety of the masts, the following instruments will be provided:

a) summary indicators for all masts (two). There are two positions, masts up and masts down. If the "up" light is on, this indicates that one or more of the masts is up. If the "down" light is on, this indicates that all masts which can be faired are faired and all others are lowered completely. Specific indicators for each mast will be provided on the Maintenance Monitoring Console.

b) an order control. This control is used to (1) indicate permission to raise, that is, the ship is operating at safe limits for mast raising. Requests to raise masts, however, must still be initiated; (2) order to fair (all masts not faired are to be lowered); and (3) order to lower (all masts are lowered at this time).

c) an emergency mast control. When activated this control will fair or lower any mast up (masts up being faired, others being lowered). This control will only be used when lowering time is critical.

3.4.4.5 Miscellaneous Instruments (Figure 3-16)
To facilitate system monitoring, the following instruments are provided:

1) a mode of operation status board identifying the present operating mode for those systems which can be operated in more than one mode. These are steering, diving, and trim (the hovering system mode is governed by the mode setting for diving). The indicators (lights) are color coded: green for Primary, amber for Secondary, and red for Tertiary. In addition, these indicators serve as specific malfunction alarms. If, for example, steering is in Primary and a malfunction should occur, the Secondary indicator would begin to pulsate directing the operator to changing modes. This will occur in conjunction with the release of an audible alarm.

2) a separate visual alarm indicator is provided for SQUIRE since it can fail without a failure to the automatic system.

3) audible alarm and control. The control can be set so that the alarm will not go off. The off position will be used when silent operation is deemed desirable. It is used more normally to shut off the alarm when activated.

In addition, several indicators are provided for use both by command (or the O.O.D.) and the ship control operator. These are:

1) cavitation indicators (qualitative), three lights signifying low, moderate, or heavy cavitation.

2) rpm indicator, which is primarily used in conjunction with the cavitation indicator for regulating the degree of cavitation via rpm changes. When ordered, these changes are communicated over the speaker mike.

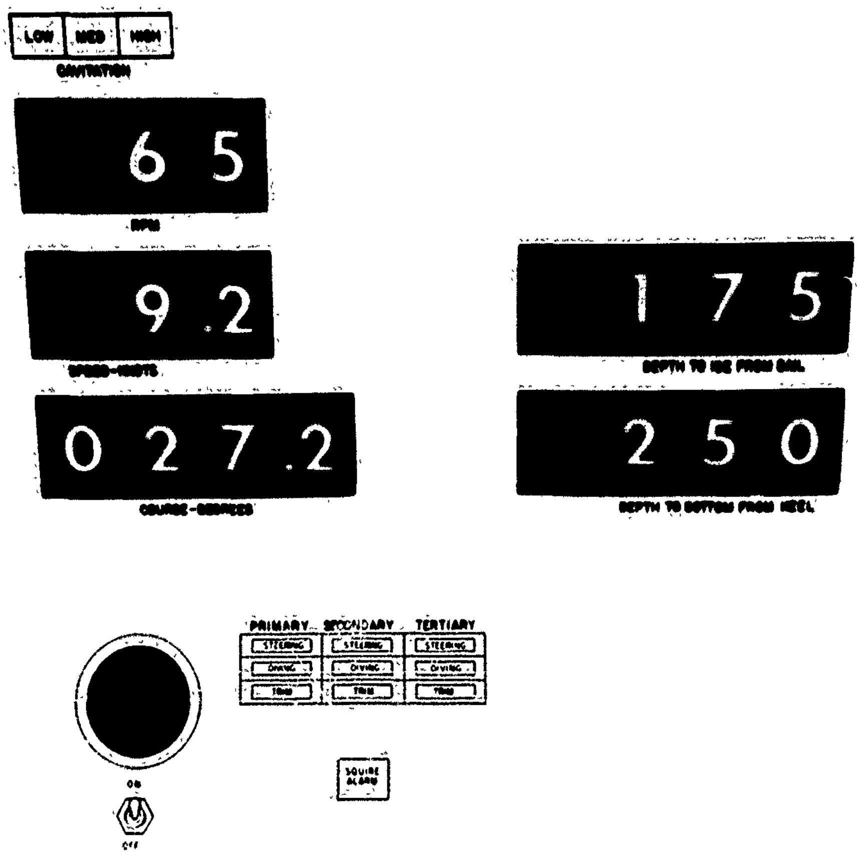

FIGURE 3-16 MISCELLANEOUS STATUS INDICATORS AND ALARM SYSTEMS

3) digital course indicator, which is used for status [illegible].

4) digital indicators showing depth to ice from keel and depth to bottom from keel. Normally, the depth to ice display will be shuttered to prevent confusion and a control for this purpose is provided. Since this information is available on [illegible], these displays serve as back-ups.

3.[illegible] REINTEGRATION

To facilitate an examination of the displays and controls [illegible] on the console in terms of the operator tasks performed and the information inputs considered necessary, Table 3-3 is presented. Table 3-3 shows the operator tasks, information requirements, displays, and controls for the Ship Control Station tasks described previously. The displays and controls listed are for manual control under normal conditions.

TABLE 3-3

SUMMARY DATA FOR THE SHIP CONTROL STATION: OPERATOR TASKS, (O.T.) INFORMATION REQUIREMENTS (I.R.), DISPLAYS (D) AND CONTROLS (C) FOR MANUAL CONTROL UNDER NORMAL CONDITIONS

O.T.	I.R.	D.	C.
Submerging			
1. Ensuring watertight integrity	a. status of hull openings	summary indicators: hatch openings, bridge hatch, hull openings	
2. Flooding MBTs	a. status of vent	vents open indicator	levers-in-groove
	b. indication of tanks flooding	tanks flooding indicator	
3. Planing Down	a. actual speed	digital indicator	
	b. depth to bottom	(b), (c), (d), (e) and (f) are incorporated in SQUIRE display	(1) max. pitch selector
	c. ordered pitch angle		(2) keyboard entry joystick
	d. ordered depth		(3) joystick
	e. actual depth		
	f. control director signal		
4. Adjusting NBT	a. desired water level		
	b. sea pressure	indicator	(1) "mark" selector
	c. NBT pressure	indicator	(2) vent flood and blow controls
	d. vent status	indicator	
	e. actual water level	indicator	

TABLE 3-3 (Cont)			
O.T.	I.R.	D.	C.
Surfacing			
1. Blowing MBTs	a. indication of tanks emptying	tanks emptying indicator	levers-in groove
	b. status of air supply	go-no go indicator	
2. Planing Up	a. actual speed	digital indicator	
	b. depth to surface	(b), (c), (d) and (e) are incorporated in SQUIRE display	(1) max. pitch selector
	c. ordered pitch		(2) keyboard entry
	d. actual depth		(3) joystick
	e. control director signal		
Depth-Seeking			
1. Planing Up (Down)	a. actual speed	digital indicator	
	b. depth to surface (bottom)	(b), (c), (d), (e) and (f) are incorporated in SQUIRE display	(1) max. pitch selector
	c ordered pitch angle		(2) keyboard entry
			(3) joystick
	d. ordered depth		
	e. actual depth		
	f. control director signal		
Depth-Keeping			
1. Holding Depth	a. ordered depth	(a), (b) and (c) are incorporated in SQUIRE display	joystick
	b. actual depth		
	c. control director signal		
2. Holding Pitch	a. ordered pitch angle	(a), (b) and (c) are incorporated in SQUIRE display	(1) neutral angle selector
	b. actual pitch angle		(2) joystick
	c. control director signal		

TABLE 3-3 (Cont)

O.T.	I.R.	D.	C.
Depth-Keeping (Cont)			
3. Effecting Trim	a. state of trim imbalance	criticality indicators	(1) trim correct control
	b. actual water levels in trim tanks	indicators	(2) "From-To" controls
			(3) pump controls
	c. ordered (appropriate) water levels in trim tanks	indicators	
	d. status of pump(s) pressure	indicators	
Piloting			
1. Adjusting Course to avoid obstacles	a. actual speed	digital indicator	
	b. location of obstacles	TV or Radar picture	(1) max. rudder selector
	c. ordered rudder angle	SQUIRE (submerged)	(2) keyboard entry
	d. ordered course	(b), (c), (d), (e) and (f) are incorporated in SQUIRE display	(3) joystick
	e. actual course		
	f. control director signal		
	g. actual rudder angle*		
Course-Seeking			
1. Turning Ship	a. actual speed	digital indicator	(1) max. rudder selector
	b. ordered rudder angle	(b), (c), (d), and (e) are incorporated in SQUIRE display	(2) keyboard entry
	c. ordered course		(3) joystick
	d. actual course		
	e. control director signal		

*On the surface, TV periscope information is available and rudder angle and gyro course indicators are employed normally.

TABLE 3-3 (Cont)			
O.T.	I.R.	D.	C.
Course-Keeping 1. Holding course	a. ordered course b. actual course c. control director signal	(a), (b) and (c) are incorporated in SQUIRE display	joystick
Speed Ordering 1. Regulating Speed	a. ordered speed b. order acknowledgment	(a) and (b) are shown on annunciator	annunciator
	c. actual speed	digital indicator	
Miscellaneous Tasks** Control Tasks 1. Operating Snorkel System	a. position of snorkel mast	up-down indicators	(1) order control (2) emergency shut-down control
	b. status of hull openings	circle-bar indicators	
2. Controlling Position of Masts	a. position of masts	summary indicators	(1) order control (2) emergency shut-down control

**Minor aspects of these two control tasks are assigned to Ship Control; all energizing and regulatory tasks are assigned to the Maintenance Monitoring Station.

IV

SONAR SURVEILLANCE

4.1 INTRODUCTION

The final form of the SUBIC Fiscal Year '65 (THRESHER class) surveillance panel faces was developed on the basis of 1) a specific, restricted definition of the sonar surveillance process, 2) a systematic analysis of the functions, tasks, and information requirements involved in the sonar surveillance process, and 3) assumptions that certain types of hardware and their associated displays and controls would be incorporated within the system.

It is the purpose of the following introductory discussion to describe the relationships among the general concepts of sonar surveillance, specifically stated functions, tasks and information requirements, and resulting panel faces. It should be noted at the outset that the particular panel faces developed, while capable of meeting general functional requirements, do not necessarily approach the ultimate configuration. The design of the panel faces reflects the SUBIC FY '65 engineering constraints and assumptions for the THRESHER (SS(N)593) class submarine.

For the development of panel faces described in this report, it was assumed that the following general types of sonar equipment and associated hardware would be incorporated within the broad category of the sonar surveillance subsystem:

1) Preformed beam, DIMUS type sonar equipment for initial detection of signal data;

2) Mechanical compensators, such as those employed in the BQS-6 sonar equipment, for target tracking and precise localization;

3) Demodulated and band shift modulated frequency recorders for initial detection and signal confirmation;

4) Sonar communication equipment of the SESCO type, with added capability provided by the central computer;

5) Classification equipment, similar to the BQQ-3 presently available.

It was also assumed that a central computer would be available for aiding the operator in such tasks as passive ranging, active ranging and range rate analysis, communications, and generated target tracking.

It should be noted that, although several types of equipment will be incorporated, there may be some common utilization of specific hardware, for example, a particular hydrophone array.

4.2 GENERAL CONCEPTS

The concept of surveillance results from the requirement of the submarine to gather information about its external environment through various sensors. A sensor is considered to consist of a receptor, which acts on or is acted upon by a given environment, an indicator, and a computing device; the basic function of a sensor is the detection and presentation of information. Examples of sensors in the submarine system are radar and ECM as well as sonar. Surveillance accomplished by means of sonar, implies "watching" of the submarine's environment through the collection and examination of waterborne sounds.

Sonar surveillance, by definition, is an integral part of the submarine system. As a system itself, the submarine is an example of "a group of activities, involving men and machines, directed toward the solution of a given set of problems"(Ref. 9, p.7). The interaction of men, machines, and their operating environment in the attaining of certain goals is inherent in the definition of system.

Within any given system or set of subsystems comprising the total system, there is a hierachy of goals or objectives, the attainment of the major goal being dependent in varying degrees on the attainment of subgoals. In the analysis of surveillance, a system is considered to be that group of man, machine, and man-machine activities which are

directed toward achieving whatever has been designated the major objective. A sub-system, it follows, is a group of activities involving men and machines which is directed toward achieving a sub-goal upon which the achievement of the major goal is dependent.

An example of a system, then, is a submarine, the major goal of which may be to seek out and destroy enemy ships. A sub-system is the group of men and machines performing surveillance activities, that is, those activities concerned with detecting, classifying, and localizing enemy ships. These activities provide information necessary for the system (submarine) to accomplish its localization and destruction goal. For the purposes of this particular report, it has been assumed that surveillance activities are limited to those listed above. It has been assumed that continuous monitoring of the environment and subsequent discovery of various natural phenomena as well as friendly ships will occur. It is not the basic function of sonar surveillance, however, as presently conceived, to detect or search for such sources of waterborne noise. Moreover, it has been assumed that sonar surveillance *per se* will not include sonar communications or fathometer operations.

The detecting, classifying, and localizing activities specified represent phases of the basic surveillance mission and serve to differentiate the surveillance mission from the Fire Control mission. Surveillance entails the process of receiving and processing signals in such a way that target characteristics (type of ship, bearing, range, D/E, speed, range rate, etc.) may be specified to Fire Control. The basic mission is, then, to inform Fire Control of presently sensed location of a target and to supply data for the prediction of future location. The disposition of such data (for example, its use for computing target course, speed, etc.) is the concern of Fire Control.

Mission, in the sense used here, is defined as a work cycle, the performance of which is required by the system or sub-system. The performance of a given work cycle or mission is equivalent to the goal directed activity noted in the definition of systems and sub-systems. Conceptualization of a mission as a cycle of work facilitates the later

division of a mission into time segments. Nevertheless, division of missions into time segments or phases does not necessarily guarantee that time segments, missions, or mission phases are not overlapping.

The surveillance mission is accomplished by an assemblage of man and machine components. The relationship between the man and machine components should be such as to maximize the probability for successful effecting of the mission. A statement of the relative value of a given system in maximizing mission success must be based upon an evaluation of the system in terms of efficiency, reliability, and logistics criteria.

4.3 ANALYSIS OF FUNCTIONS AND TASKS

In order to delineate the job of the man-machine assemblage, an analysis of each mission phase (for example, detection) into its component functions and tasks was undertaken. Function is defined as a gross activity or performance of the system which contributes toward the obtaining of system's objectives or goals. Thus, obtaining a target's bearing is a function of the surveillance sub-system. Functions may be assigned to either men or machines or to combinations of men and machines. Tasks, that is, those specific activities necessary to accomplish a given function, have been determined. Within the work cycle of localization a task, for example, may be the nulling of a bearing deviation signal to obtain a precise bearing. Insofar as possible the functions and tasks have been stated in sequential order.

4.4 TASK ALLOCATION

The tasks isolated during the function and task analysis fall into four categories: perceptual, decisional, operational, and computational. A perceptual task, akin to monitoring or vigilance, involves the sensing and "registering" of environmental conditions, whether dynamic or static, in a form that permits utilization of relevant data. A decisional task involves the choosing among a number of alternatives or an inferring that a particular situation exists. An operational task involves the mechanical manipulation of equipment. A computational

task involves the performing of a complex or time-consuming numerical calculation or the making of a numerical estimate. It should be recognized, however, that the division of tasks into the four defined types is somewhat arbitrary. In no sense should the division imply that a task of a certain type is limited in characteristics strictly to those of that given type. A discrimination task, for example, involves both perceiving certain stimuli and deciding how they relate to one another.

The breakdown of the task types into four gross classifications does, nevertheless, facilitate the assignment of each to a man or machine component. The allocation of each task to a man or machine component is based upon the relative facility with which each component performs the given task type. Considerable information (Ref. 3 and 8) is available on the relative facility of man and machine in performing the task types.

Decision tasks have been assigned to man because of his adaptive ability in uncertain situations and his long-term storage capability. Perceptual tasks have been assigned to man because of man's ability to recognize signals in a background of noise and his ability to isolate patterns in a variety of situations. Operational tasks have been assigned to either component on the basis of the relative skill of each in performing a given manipulation. Computational tasks have been allocated to machines because of the ability of machines to perform deductive, mathematical operations. The nature of the man-machine interaction was decided following the allocation of tasks.

4.5 INFORMATION REQUIREMENTS AND CONSOLE DESIGN

The console developed on the basis of the foregoing analysis serves as a physical link between the operator and the machine with which he must interact to accomplish the system's mission. The tasks have been analyzed to determine relevant information requirements. The requirements represent the flow of information between man and machine and determine what is to be displayed. What, how, and where information is to be displayed is related to the "criticality" of that information.

Criticality is determined basically by the extent to which a given item of information is related to mission success.

The statement of information requirements and their characteristics serves as a guide in specifying requirements for the design of an operationally efficient console. An operationally efficient console is one which provides required information in a form that is maximally useful to the operator for his contribution to the success of the entire system's mission. The particular form in which information will be maximally useful is dependent upon man's capabilities as an information receiver, processor, and transmitter. One must ask, upon the decision that the operator should perform a given task, for example, spectrum analysis, through what sense modality or what combination of modalities (visual, aural, tactual) should frequency information be presented. Basically, the required information (that is, that upon which the performance of a given task depends) can be used only to the extent that its presentation is available and meaningful to the operator.

The development of particular displays and controls requires knowledge of man's perceptual-response, information-processing, and decision-making characteristics. Systematically collected data describing some of man's responses to various forms of information presentation are available.

Guidelines (for example, Human Factors Design Standards for the Fleet Ballistic Missile Weapon System, 1960; Fitts, in Handbook of Experimental Psychology; Human Factors in Undersea Warfare, 1949; and Havron and Jenkins, 1961), which have been formulated on the basis of such data, have been used in the present console design where applicable (Ref. 5,2,7,4).

The analysis of information requirements was derived from a survey of the manuals available for presently used sonar systems (Ref. 1,6). An attempt was made to generalize detailed requirements contained in the manuals. Even within the general framework, however, the capabilities

and limitations of the systems examined may be reflected. At the time the analysis was undertaken, passive ranging and classification manuals were not available.

4.6 AREAS FOR CONTINUED WORK

It was stated at the outset that the surveillance console proposed was intended to satisfy SUBIC FY '65 requirements. The function, task, and information requirement analysis was based upon available but not necessarily complete data. Little modification could be recommended in, for example, the area of classification, since there was not sufficient time to change basically the present display-control concept.

In long-range planning, however, a further, more detailed refinement of the function and task descriptions should be considered. Specification of at least the following areas should be undertaken:

1) critical malfunctions

2) speed and accuracy with which information must be obtained and processed

3) frequency of task occurrence.

4.7 DESCRIPTION OF FUNCTIONS, TASKS, AND INFORMATION REQUIREMENTS

4.7.1 Phase I Initial Search and Detection

Function 1) Selection of search mode

Task 1A (P-D)* Choice between

(1) active
(2) passive

Information Requirement 1A (P-D)

(1) Commanding officer's order based upon

a) likelihood of possible targets in area
b) proximity of targets
c) own ship conditions (for example, weapon capability)
d) necessity or desirability of maintaining own security

*P = Perceptual; D = Decisional

Function 2) Creation of search and detection environment upon choice of passive mode

Task 2A (D-O)* Choice of particular passive search gear, if alternatives are available,

Information Requirement 2A (D-O)

(1) Conditions in external environment

a) sound conditions dependent upon sea-state, temperature, etc.
b) natural sounds present
c) position of close land.

(2) Conditions in internal environment

a) own ship's noise
b) own ship's speed
c) own ship's depth
d) own ship's course

Task 2B (O) Activation of appropriate passive sub-system

Information Requirement 2B (O)

(1) Condition of chosen gear: operative, inoperative, malfunctioning

(2) Sub-system inputs

a) own ship's speed
b) ordered depression/elevation angle at which to search
c) desired bearing designation (TRUE, REL)

Function 3) Isolation of signal representing possible target, passive mode, and preliminary determination of contact bearing, depression/elevation

Task 3A (P) Scanning for contact

Task 3B (P-D) Decision that contact is present

*O = Operational

Information Requirement 3B (P-D)

(1) significant change in signal to noise ratio

Task 3C (O-P) Estimate of target bearing and D/E

Information Requirement 3C (O-P)

(1) point of maximum signal intensity

Task 3D (O) Coding signal for identification purposes

Information Requirement 3D (O)

(1) characteristics (bearing and depth) estimated from Task C
(2) available classification data
(3) time of initial contact

Function 4) Transmission of bearing and depth information to Fire Control

Task 4A (D-O) Selection of data for transmission

Information Requirement 4A (D-O)

(1) obtained estimates of bearing and depth
(2) accuracy probability of obtained signals

Task 4B (O) Activation of transmitting equipment

Information Requirement 4B (O)

(1) operative, inoperative, or malfunctioning condition of gear

(2) feedback from Fire Control denoting reception of signal and/or request for additional information

Function 5) Creation of search and detection environment upon choice of active mode

Task 5A (P-D-O) Selection of single or continuous ping transmission mode

Information Requirement 5A (P-D-O)

(1) command to ping actively
(2) specification of single or continuous ping

Task 5B (P-D-O) Selection of width of transmitting beam (e.g., 6°, 360°, etc.)

Information Requirement 5B (P-D-O)

(1) command specification of transmitting beam width based upon

a) operational conditions
b) most probable location of contacts
c) most probable identity of target (ice, mine-field, enemy submarine, etc.)

Task 5C (O) Activation of active system

Information Requirement 5C (O)

(1) operative, inoperative, or malfunctioning condition of chosen system
(2) desired bearing designation (True or Relative)
(3) selected ping mode, beam width and search area

Function 6) Isolation of signal representing possible target and preliminary determination of contact bearing, depression/elevation, and range

Task 6A (P) Scanning for contact

Task 6B (P-D) Decision that contact is present

Information Requirement 6B (P-D)

(1) Evidence of return echo (significant, perceptible change in signal to noise ratio)

Task 6C (O-P) Estimate of target's bearing and depth

Information Requirement 6C (O-P)

(1) point of maximum signal intensity

Task 6D (O-C)* Estimate of target's range,

*C = Computational

Information Requirement 6D (O-C)

(1) time of active transmission
(2) time of return echo
(3) difference between time (1) and time (2)

Task 6E (O-C) Estimate of target's speed and direction of motion through Doppler technique

Information Requirement 6E (O-C)

(1) reverberating pitch
(2) return echo pitch
(3) difference between pitch (1) and pitch (2)

Task 6F (O) Coding of signal for identification purposes

Information Requirement 6F (O)

(1) characteristics (bearing, depth, range, speed) obtained through Tasks 6C, D, and E
(2) available classification data
(3) time of target's initial detection
(4) source of information

Function 7) Transmission of bearing, depth, range, and speed information to Fire Control

Task 7A (D-O) Selection of data for transmission

Information Requirement 7A (D-O)

(1) obtained estimates in bearing, depth, range, and speed
(2) accuracy probability of obtained signals

Task 7B (O) Activation of transmission device

Information Requirement 7B (O)

(1) operative, inoperative, or malfunctioning condition of gear
(2) feedback from Fire Control denoting reception of signal and/or desire for more information

4.7.2 Phase II Classification

Function 1) Selection of signal for classification

Task 1A (P-D) Selection of signal on basis of C.O.'s orders

Information Requirement 1A (P-D)

(1) target priorities as determined by C.O.
(2) standing orders: classify all targets upon detection

Function 2) Establishing classification: aural means

Task 2A (D) Choice of signal mediating source:

(1) conformal hydrophone array
(2) test signal "store"
(3) classification hydrophone array

Task 2B (D) Choice of position of hydrophone array:

(1) bow
(2) bow and midships
(3) bow and stern
(4) bow, midships, and stern

Information Requirement 2A (D) and 2B (D)

(1) optimal array for:

a) given target bearing
b) estimated target range
c) target's operating condition
d) own ship's operating condition

Task 2C (O) Activation of chosen hydrophone array:

Information Requirement 2C (O)

(1) condition of chosen array: operative, inoperative
(2) sub-system inputs
a) hydrophone array position
b) signal mediating source

Task 2D (P) Recognition of changes in target's:

(1) loudness
(2) quality
(3) rate of rhythmic pulsation

Information Requirement 2D (P)

(1) target signals discriminable against background noise; presence of rhythmic propeller beat

Task 2E (P-D) Classification of signals into probable source category

(1) light craft
(2) warship
(3) cargo ship
(4) surf
(5) marine life
(6) mines

Information Requirement 2E (P-D)

(1) characteristic screw sounds associated with ship categories

(2) characteristic sounds associated with other sources, that is, ambient noise produced by surf, weather, fish, etc.

(3) level and characteristics of self noise from bow planes, air, trim pump, motor generators, own screws, rudder, etc.

Task 2F (P-D) Estimation of speed and speed changes from turn or beat-counting

Information Requirement 2F (P-D)

(1) discriminable accent in rhythm of signals from target's propellers

(2) discriminable beats from target's propellers

Function 3) Determination of classification: visual and aural means

Task 3A (D) - As in Task 2A

Task 3B (D) - As in Task [illegible]

Task 3C (O) - As in Task 2

Task 3D (P-D) Integration of spectral analysis to produce appropriate classification of target

Information Requirement 3D (P-D)

(1) frequency spectrum analysis
(2) noise level
 a) signal
 b) ambient
 c) self
(3) hydrophone array bearing
(4) test signals
(5) reference index of target screw beats, other rotating machinery characteristics, etc.

Task 3E (O) Coding of classified signal for future reference purposes

Information Requirement 3E (O)

(1) results of classification procedure
(2) C.O.'s orders on target coding
(3) previous coding of signal in detection phase

Task 3F (P-O) Active transmission to identify friend or foe

Information Requirement 3F (P-O)

(1) C.O.'s order to identify through single ping
(2) operative, inoperative, or malfunctioning condition of equipment
(3) contact bearing, depth, and estimated range

Task 3G (P) Monitoring for IFF signal

Information Requirement 3G (P)

(1) returned signal

Task 3H (O-P) Identifying friend through SESCO passive operation: reception of SESCO message signal

Information Requirement 3H (O-P)

(1) operative, inoperative, or malfunctioning condition of equipment
(2) source (C.O. or operator) of transducer beam position
(3) expected bearing of contact
(4) expected range of contact
(5) expected range rate of contact
(6) scheduled time of contact
(7) presence of acquisition or false alarm signal

Task 3I (O) Transmission of signal classification data to Fire Control

(1) classified and coded signal with available information on bearing, range, range rate, time

(2) feedback from Fire Control indicating reception of signal and/or request for additional information

4.7.3 Phase III Localizing and Tracking

Function 1) Selection of signal for precise localization

Task 1A (P-D) Choice of specific signal on basis of command orders

Information Requirement 1A (P-D) Content of command orders:

(1) target priorities ("target threat evaluation")
(2) standing orders to localize targets upon detection irrespective of completeness of classification
(3) standing order to localize certain targets, dependent upon results of classification
(4) available classification data
(5) strength of signal in relation to that of other signals which may be present simultaneously

Function 2) Selection of active or passive operating mode

Task 2A (P-D-O) Choice between active and passive mode

Information Requirement 2A (P-D-O)

(1) command orders based upon:
  a) security requirements
  b) criticality of accurate range information
  c) estimated range of target
  d) tactical situation

Task 2B (O) Activation of mode chosen

Information Requirement 2B (O)

(1) operative, inoperative, or malfunctioning condition of chosen system

(2) location estimate of previously detected signal

(3) own ship speed

Function 3) Determination of bearing and D/E, upon selection of <u>passive</u> operation

Task 3A (P-O) Locating detected target

Information Requirement 3A (P-O)

(1) signal discriminable from background noise

(2) deviation of receiving beam from contact:

  a) gross deviation
  b) horizontal (r-l) deviation for bearing
  c) vertical (u-d) deviation for D/E

(3) point of maximum signal intensity

Task 3B (O) Coding of signal for identification purposes (If signal not previously coded under Phase I)

Information Requirement 3B (O)

(1) characteristics obtained during Task A
(2) available classification data

(3) time of localization
(4) source of information

Function 4) Transmission of bearing and D/E angle data to Fire Control and initiation of aided track in bearing and/or D/E

Task 4A (D-O) Selection of data for transmission to F.C.

Information Requirement 4A (D-O)

(1) obtained estimates in bearing, and D/E
(2) accuracy probability of obtained signals

Task 4B (O) Activation of transmitting device

Information Requirement 4B (O)

(1) operative, inoperative, or malfunctioning condition of gear
(2) feedback from F.C. denoting reception of signal or desire for more information

Task 4C (P-O) Activation of automatic target follow (ATF) in D/E and/or azimuth

Information Requirement 4C (P-O)

(1) null condition of deviation of beam from contact
(2) D/E and/or bearing mark to F.C.

Task 4D (P-O) Activation of generated target tracking (GTT) in azimuth

Information Requirement 4D (P-O)

(1) presence of sufficient contact information at F.C. to generate target track

Function 5) Determination of range, upon selection of <u>passive</u> operation

Task 5A (O) Activation of passive ranging equipment

Information Requirement 5A (O)

(1) operative, inoperative, or malfunctioning condition of equipment

(2) condition of ambient (isotropic and structure borne) noise

(3) vertical arrival angle
(4) sound velocity qualities

Task 5B (P-O-C) Obtaining range of detected target

(1) selecting sector of area for range establishment
(2) aligning correlograms

Information Requirement 5B (P-O-C)

(1) sector appropriate for passive ranging
(2) presence of signal discriminable from noise background
(3) condition of optimized post-integration time and sweep rates

Function 6) Transmission of range and additional bearing data to F.C.

Task 6A (D-O) Selection of data for transmission

Information Requirement 6A (D-O)

(1) obtained range and bearing
(2) accuracy probability of obtained signal (perhaps compared with independent estimate of parameters)

Task 6B (O) Activation of transmitting device

Information Requirement 6B (O)

(1) operative, inoperative, or malfunctioning of gear
(2) feedback from F.C. indicating reception of data or desire for more information

Function 7) Determination of bearing and D/E, and Range upon selection of <u>active</u> operation

Task 7A (P-D) Choice of single or continuous ping mode

Information Requirement 7A (P-D)

(1) content of C.O.'s order based upon:
a) requirements of tactical situation
b) necessity of maintaining own ship's position secrecy

Task 7B (P-D) Choice between "listen" mode or specific beam width, for example:

a) single beam
b) omni beam
c) tri-beam
d) tri-beam omni

Information Requirement 7B (P-D)

(1) C.O.'s order based upon tactical situation requirements and need for

a) 360° pulse for active search and tracking (omni)
b) long range contact tracking for precise range and bearing in 6° sector (single)
c) long range searching in 18° sector (tri-beam)
d) long range searching and 360° coverage (tri-beam omni)

Task 7C (O) Activation of chosen mode

Information Requirement 7C (O)

(1) operative, inoperative, or malfunctioning condition of mode chosen

(2) inputs appropriate to mode chosen (detailed in alternate Tasks D through D4)

(Alternate) Task 7D (O-P) Establishment of bearing and D/E upon choice of "listen" mode

Information Requirement 7D (O-P)

(1) presence of significant signal to noise ratio - maximum bearing signal and maximum D/E signal

(Alternate) Task $7D_1$ (O-P) Establishment of bearing and range upon choice of omni-directional operation

Information Requirement $7D_1$ (O-P)

(1) appropriate switch pulse length
(2) "range of the day"

(3) significant signal to noise ratio within selected range

(4) point of maximum target signal

(Alternate) Task $7D_2$ (O-P) Establishment of bearing range and D/E upon choice of directional (for example, 6° beam-width operation)

Information Requirement $7D_2$ (O-P)

(1) anticipated range

(2) appropriate pulse length and power output

(3) presence of signal discriminable from noise background for initial bearing

(4) bearing of target obtained prior to initiation of single-ping echo-ranging

(5) deviation of signal from range of contact - return echo

(6) deviation of receiving beam from contact in D/E

(Alternate) Task $7D_3$ (O-P) Establishment of bearing and range and D/E upon choice of directional operation (for example, 18° beam-width)

Information Requirement $7D_3$ (O-P)

(1) appropriate pulse length (ordered) and power output

(2) ordered range

(3) ordered bearing characteristic (REL or TRUE)

(4) own ship's course

(5) bearing of sector to be searched relative to own ship's course

(6) presence of signal discriminable from noise background - return echo

(7) beam from which contact was detected

(8) deviation of return-echo signal from range of contact

(9) deviation of return-echo signal from contact D/E

(Alternate) Task $7D_4$ (O-P) Establishing bearing, range, and depth upon choice of combined directional and omni-directional beam width (for example, tri-beam omni operation)

Information Requirement $7D_4$ (O-P)

(1) ordered pulse length
(2) ordered range
(3) own ship's course
(4) bearing of sector relative to own ship's course
(5) ordered bearing: relative or true
(6) presence of signal discriminable from noise background
(7) beam upon which target was detected
(8) deviation of return echo signal from range of contact
(9) deviation of return-echo signal from contact D/E

Function 8) Transmission of range, bearing, and D/E data to F.C. and initiation of tracking

Task 8A (D-O) Selection of data for transmission

Information Requirement 8A (D-O)

(1) obtained data from employed mode of operation, for example,

a) listen mode: obtained bearing and D/E
b) omni operation: obtained bearing and range
c) single operation: obtained bearing, range and D/E
d) tri-beam operation: obtained bearing, range and D/E
e) tri-beam omni operation: obtained bearing, range and D/E

(2) probability of accuracy of obtained data

Task 8B (O) Activation of transmitting device

Information Requirement 8B (O)

(1) operative, inoperative, or malfunctioning condition of transmitting device

(2) feedback from F.C. control indicating reception of signal and/or desire for more information

Task 8C (P-D-O) Activation of aided tracking

Information Requirement 8C (P-D-O)

(1) type of tracking (range, bearing, range-bearing) desired
(2) sufficient-information condition at fire control (range)
(3) sufficient-information condition at computer (range and/or bearing)

Function 9) Determination of range rate, <u>active</u> operation

Task 9A (O) Activation of equipment

Information Requirement 9A (O)

(1) operative, inoperative, or malfunctioning condition of equipment
(2) water salinity and temperature
(3) mode (single-ping or continuous) of operation of active equipment

Task 9B (P-D-O) Selection or storing of immediate display for analysis

Information Requirement 9B (P-D-O)

(1) presence of target signal discriminable from background
(2) obtained range of target
(3) specific display to be stored
(4) identity (code) of stored signal

Task 9C (P-O-C) Performance of range rate analysis

Information Requirement 9C (P-O-C)

(1) frequency of transmitted beam
(2) deviation of frequency of return echo from frequency of transmitted beam

Function 10) Transmission of range and range rate data to computer and F.C. for tracking

Task 10A (D-O) Selection of data for transmission

Information Requirement 10A (D-O)

(1) obtained range

(2) obtained range rate
(3) accuracy probability of obtained parameters

Task 10B (0) Activation of data transmission device

Information Requirement 10B (0)

(1) operative, inoperative, or malfunctioning condition of equipment
(2) mode of operation (single or continuous)
(3) feedback from computer or F.C. indicating reception of information and/or need for more information

4.8 OVERVIEW OF PANEL FACE DETAIL DISCUSSION

The foregoing analysis of functions, tasks, and information requirements contributed to the development of the panel faces recommended in this section. The development was also influenced by the nature of the mission assumed for sonar surveillance and by the strong recommendations from engineering personnel that certain types of equipment be incorporated within the console.

In the mission breakdown, three phases were isolated: (1) initial search and detection, (2) classification, and (3) localizing and tracking. The basic division of the console into operator stations was predicated on the mission phase breakdown. It was the initial guiding assumption that one operator would be responsible for only one of the mission phases. It was not, however, an assumption that the phases would in any sense be mutually exclusive or non-overlapping in time. Indeed, the probability that considerable overlap would occur prompted a design which would allow maximum transmission of information from operator to operator.

The proposed console incorporates five stations, as indicated on Figures 4-1 thru 4-5. These stations consist of: (1) initial detection, (2) frequency monitoring, (3) classification, (4) passive tracking, and (5) active tracking. The operator's stations for passive initial detection and frequency monitoring are located adjacent to each other, and are bounded on the left at a 45° angle by the tracking stations and

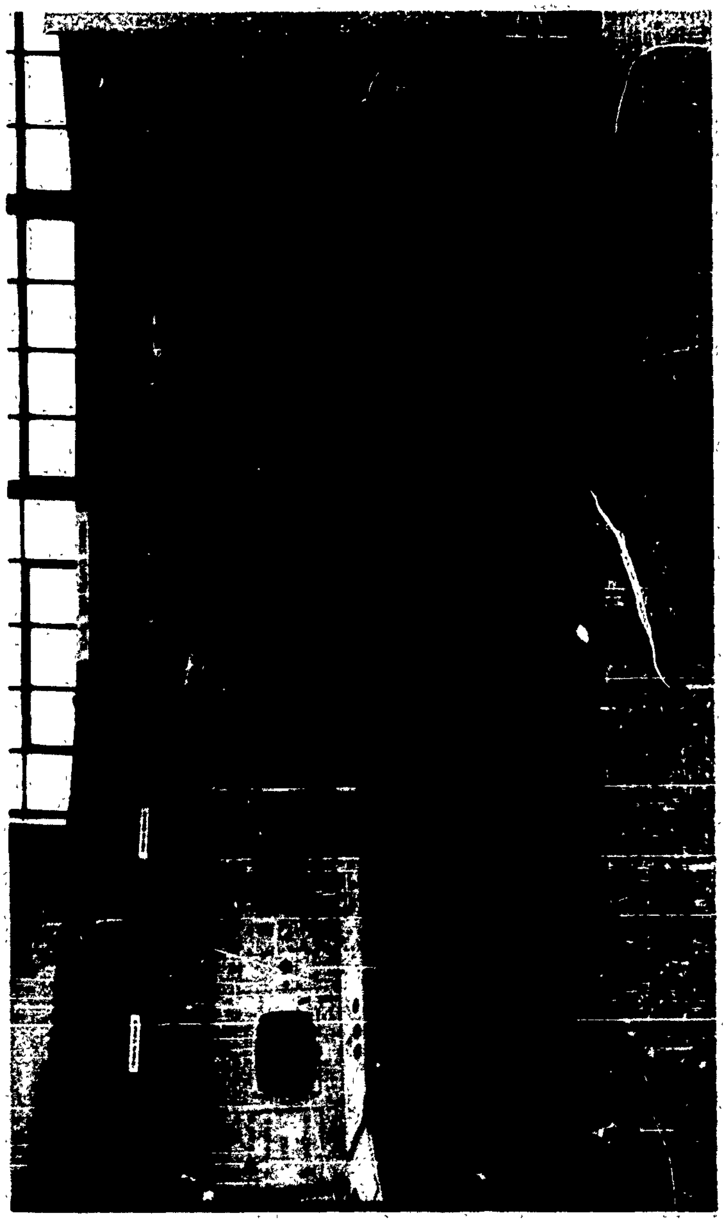

FIGURE 4-1 SONAR SURVEILLANCE STATIONS

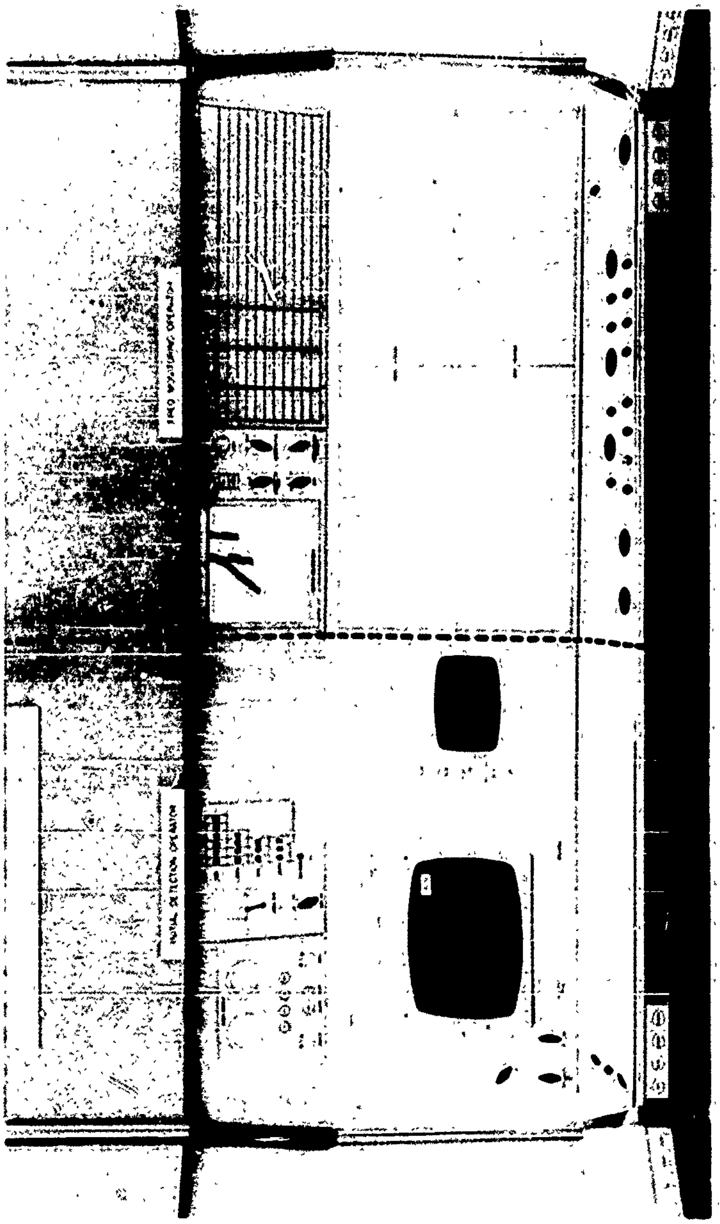

FIGURE 4-2 INITIAL DETECTION STATION | FIGURE 4-3 FREQUENCY MONITORING STATION

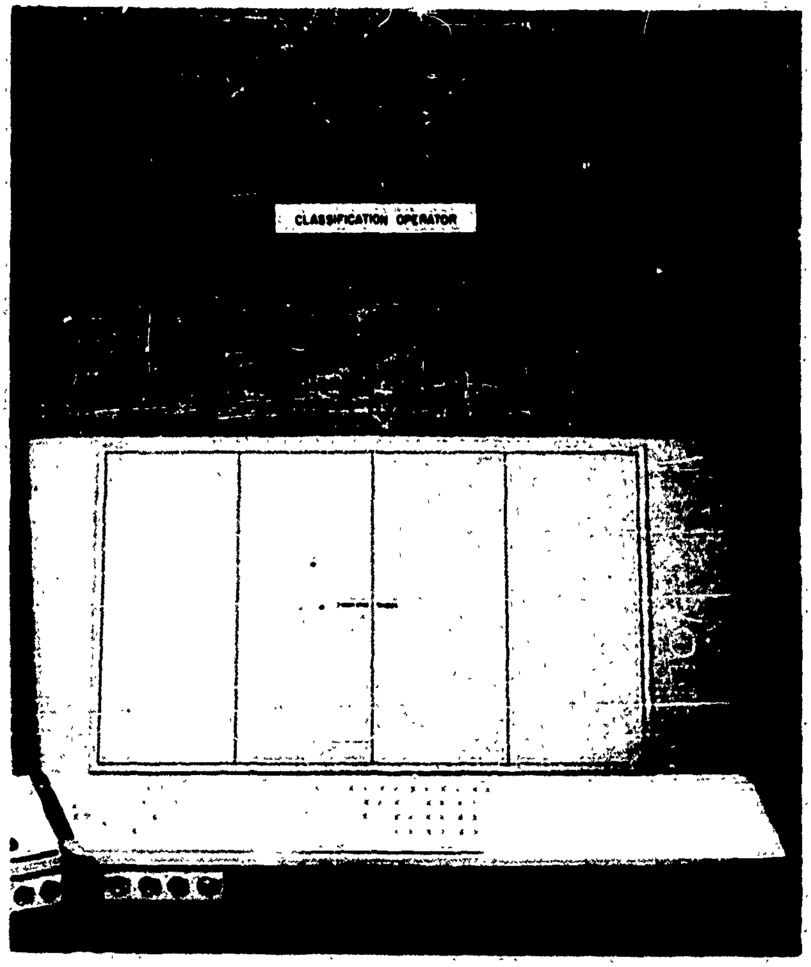

FIGURE 4-4 CLASSIFICATION STATION

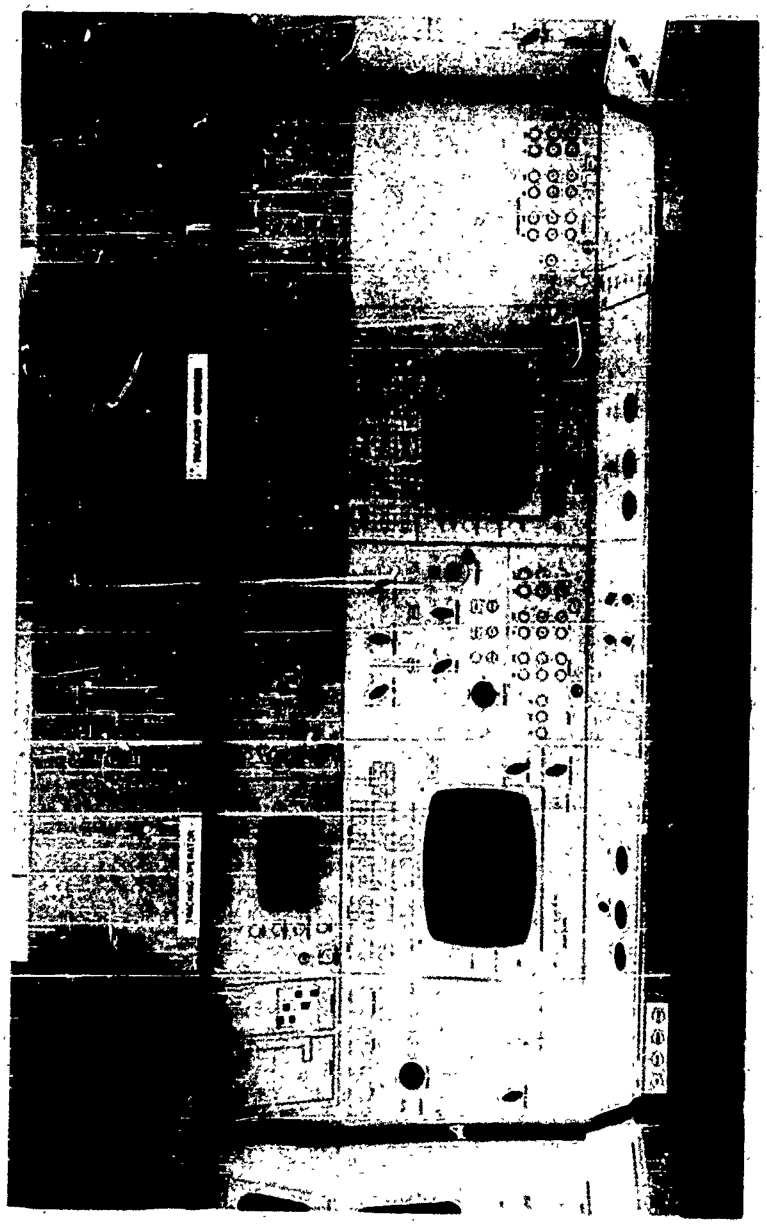

FIGURE 4-5 TRACKING STATION

on the right at a 45° angle by the classification station. The initial detection and frequency monitoring stations have been placed together because the activities occurring at each are complementary. The frequency monitoring station accomplishes the transition from initial detection to classification: it can provide initial indication of a signal, it can confirm (or fail to confirm) the presence of a signal detected elsewhere, and it can provide some refined spectral frequency information basic to classification.

The initial detection station has been given a relatively centralized position because the accomplishment of its mission phase necessarily precedes the accomplishment of the other two phases, that is, classification and localization of a specific target. Nevertheless, the first mission phase is continuous and concurrent with the other two phases with respect to the mission as a whole.

The classification station has been placed to the right of the initial detection and frequency monitoring stations because the utilization of identical information (frequency data and bearing data integrated over a period of time) contributes to the success of both mission phases. The stations assigned to localization tasks which are dependent upon detection, but not necessarily upon classification, are located at the left of the initial detection station. The passive station, which will be used under most normal conditions, is at the direct left. The active tracking station, which also provides active search and communications, is at the far left of the console, in close proximity to the Fire Control console. The five stations are described individually below.

4.9 PASSIVE INITIAL DETECTION STATION (Fig. 4-1, 4-2)
At the Initial Detection Station it is the operator's primary responsibility to isolate signals from background noise. Having perceived what he considers to represent a signal, the operator proceeds to confirm the signal characteristics and to establish the signal's bearing and depression/elevation as well as he can.

The present paper assumes that passive sonar equipment (for example, a preformed beam system) will be of primary importance in the initial detection phase, although other equipment may also provide data useful for initial detection. Initial detection signals can be provided by the spherical array, if necessary. The DIMUS-type system will be capable of providing data from both broad and four selected fixed frequency bands. Moreover, the assumed system provides the capability for selecting post-detection integration intervals, continuous 360° detection, and statistical testing for signal presence.

The initial detection station is approximately 35 inches in width. Its vertical dimensions are: header panel, 15 inches; upper panel, 12 inches; middle panel, 22 inches; and bottom panel, 10 inches. The upper panel is tilted 20° toward the seated operator and the middle panel is positioned 10° away from the seated operator. The viewing angles relative to the upper and middle panels are well within the tolerances of the seated operator.

4.9.1 <u>Controls and Displays on Passive Initial Detection Panel</u>
The controls and displays listed below appear at the initial detection station.

<u>Upper Panel</u>

1) Signal Level Meter

2) Two-position SUM/DIFF Switch

3) Sonar Intercept Displays

   a) Frequency meter
   b) Bearing indicator

4) Sonar Intercept Controls

   a) On, automatic, manual, and sensitivity pushbuttons
   b) Audio reset and video reset lighted pushbuttons
   c) Dimmer and gain control knobs

5) Digital Readout Indicators for own ship's time, RPM, depth, course, and sea state.

Middle Panel

1) Warning Indicator Lights for Water, Interlock, Battle Short, Excess Duty, and Regulator Off

2) On-off Indicator Lights for the Major Sonar Equipment

3) Signal, Weapon Alarms - Indicator Lights

4) Relative and Unstabilized Indicator Lights

5) Major Initial Detection Display - 9-inch x 12-inch CRT

6) CRT Adjustment Knobs for Gain, Focus, Scale Illumination, and Intensity

7) Other Controls for Initial Detection CRT

a) Integration time selector switch
b) Statistical test selector switch
c) Full test display pushbutton
d) Frequency back-lighted pushbuttons and associated "sequence" and "compare" pushbuttons
e) D/E back-lighted pushbuttons and associated "sequence" and "compare" pushbuttons

8) Digital Readouts for Target Number, Bearing

9) Frequency Spectrum Shaper, a 6-inch x 4-inch CRT

10) Pushbutton for erasing display

11) Pantograph

12) Focus, intensity, scale illumination and gain control knobs

13) Selector switch for choosing between spherical compensators and DIMUS for ID

Lower Panel

1) Pushbuttons for on, auto, manual, raw, stored data, and knob for controlling gain.

2) GTT enter, GTT up-date, and GTT erase pushbuttons

3) Bearing (audio and video) finger wheels

4) Audio attenuation and ICS gain control knobs

5) Intensity control knobs for audio, video, and stern cursors

6) Selector switches for search rate, video/audio slave, auto/manual search

7) Readout pushbuttons for broad-band raw, broad-band processed, and fixed-band raw

8) Phone jacks for ICS, mike, 2 sonars

9) Digital keyboard, keyboard readout, "next number" readout, clear pushbutton

10) Pushbuttons for entering assigned contact number and erasing contact number

11) Pushbuttons for initiating ATF and marking manually

4.9.2 Description of Principal Displays and Operations

The major initial detection display is a 9-inch by 12-inch CRT which presents azimuth information along the x-axis with signal strength deflected vertically. The scope is divided into two sweeps, the upper providing the presentation of broad band information and the lower the presentation of information from four fixed bands. Information from both broad and fixed band (scanned sequentially) sources appears simultaneously, since it is possible that a signal may be detected initially on either the broad or narrow band. In broad band, a continuous statistical test is automatically scanned through the raw data and the results are displayed. The operator may select the type (that is, X^2, weighted mean, or other) of test he wishes to employ. The results of the test are displayed in a "window", which moves across the face of the scope. The use of the window serves to avoid "clutter" which might result from the display of the test at all bearings simultaneously. It is possible, however, for the man to order the test to be displayed across the entire range of the sweep by depressing the

"Full Test Display" pushbutton. A signal is indicated by a pronounced peak over a given bearing sector. The peak persists for a period of time equal to the repetition rate of the sweep.

The operator is able to select either "auto scan", a mode in which each of three possible integration times is scanned automatically in succession, or specifically, one of the three integration times for continued data presentation.

Having established the presence of a signal on the broad band, the operator proceeds to determine the bearing of the signal by positioning a cursor over the bearing sector to be refined. He accomplishes this action by rotating a finger wheel. Subsequently, he can select the "best" D/E angle (that is, D/E at which the signal is strongest) at which to listen by depressing a D/E compare pushbutton. Normally, D/E's are being scanned sequentially and the D/E sequence pushbutton is depressed. The "best" D/E is indicated by the lighting of one of three back-lighted pushbuttons. Having estimated bearing by aligning the cursor, and D/E by depressing the D/E compare pushbutton, he proceeds to obtain bearing readout based upon either raw or statistically processed data. Readout pushbuttons for raw and statistically processed data are provided on the lower panel.

Contact numbers are assigned manually by the operator. If not already on the contact, the initial detection operator aligns his video cursor to the contact he wishes to number. He observes his "next number" readout to determine what number should be assigned. He selects the appropriate number from the keyboard and checks the keyboard readout. He than enters the selected number by depressing the "assign contact number". This action results in the simultaneous assignment of a contact number and a tick mark below the scale at the top of the display.

When the operator wishes to transmit the initial detection data to Fire Control, he depresses the ATF pushbutton. The symbol for ATF is a ring which surrounds a dot. If ATF is occurring, the dot will remain centered in the ring. If the dot is not centered, the operator

terminates ATF by initiating GTT. When he wishes to maintain rough track at the initial detection display via GTT, he aligns his cursor to the appropriate bearing and depresses the "GTT initiate" pushbutton. Bearing information can be transmitted to fire control by means of the "mark-manual" pushbutton.

The presence of a signal may be initially perceptible on the fixed band display in the lower sweep of the scope. Normally, the four fixed bands are scanned sequentially. If a signal is detected on the narrow band display, the operator can order a comparison of frequency bands to obtain the optimum listening frequency band at the bearing of the cursor. The bearing sector to be investigated is selected, as with the broad band display, by positioning a cursor with the video finger wheel. The best listening D/E for the particular bearing sector to which the cursor is positioned may also be obtained by depressing the D/E compare pushbutton. The bearing readout derived from fixed band information is obtained in a manner identical to that employed with broad band information. At the initial detection station, moreover, the operator may choose a particular D/E angle and also a fixed band for scanning purposes, if he wishes, by depressing the appropriate back-lighted pushbutton.

The initial detection station, as noted previously, also has the capability for gross target tracking. Under normal operating conditions, gross target tracking is maintained on the initial detection display automatically; however, appropriate controls are also provided for manual back-up. If the operator wishes to maintain a gross track manually on a given signal which has moved, he positions his cursor on the symbol of the original, marked bearing line of the signal and depresses the GTT update pushbutton, which lights. He then re-aligns his cursor to the new position and depresses the GTT update pushbutton a second time. The second depression results in the extinguishing of the light and generation of new bearing rate for the updated symbol. When a rough track is initiated, a horizontal line is superimposed over the newly positioned target symbol to form a cross. The target number is automatically repositioned.

The passive intial detection display is flexible in that it permits utilization of information from broad and/or fixed band frequencies. Target number coding is done manually in sequential order, but the obtained target data with the appropriate target numbers are presented automatically to the tracking stations. Target data can be sent to Fire Control by means of the ATF or manual mark capability.

The initial detection station also provides warning indicator lights (for example, "battle short," excess duty," etc.) power-on pushbuttons, and sonar intercept displays.

The operator's controls for his aural displays (earphones) are located both at the right of the initial detection display and on the lower panel. The operator can accomplish audio frequency spectrum shaping by adjusting frequency distribution as presented on the CRT at the right of the major display. He can essentially "write" a spectrum shape on the CRT by using a pantograph. Associated controls for erasing spectrum patterns are present. Broad band input may be so shaped.

Switches for selecting auto or manual audio search, search rate, video/audio slave, as well as knobs for audio attenuation, ICS gain, and cursor intensity have been provided. In automatic scan, the audio display presents continous scanning of all bearings. If the operator wishes to control audio scanning manually, he increases the gain of the audio cursor, presented on the CRT, and controls its position by means of the audio cursor finger wheel. Normally the video cursor is slaved to the audio input with respect to bearing search. However, the video can be operated independently if the "manual video" position of the switch is chosen.

Located in the lower right-hand corner of the lower panel are controls for making aural comparisons of raw data (containing "suspected" signal) and stored data (noise, pre-recorded under no-signal conditions). The sources of sound can alternate at a pre-set rate in the automatic mode or can vary at a rate set by the operator who manually adjusts (by means of pushbuttons) the duration of each source of data.

4.10 FREQUENCY MONITORING STATION (Fig. 4-3)
At the frequency monitoring station, a signal may be detected for the first time or a suspected signal's presence may be confirmed. The frequency monitoring station is approximately 44 inches in width. The other dimensions conform to those given for the initial detection station.

4.10.1 Controls and Displays at Frequency Monitoring Station
The following displays and controls have been placed at the frequency monitoring station:

Upper Panel

1) Bearing Time Recorder
2) Bearing Time Recorder Controls
   a) ON pushbutton
   b) Time integration selector switch
   c) Indicator lights for relative or unstabilized operation
   d) Knob for selecting D/E angle to be searched
   e) Paper advance/speed selector switch/pushbutton combination
   f) Spherical/DIMUS system selector switch
   g) Gain control knob
3) Status Board

Middle Panel

1) 4-channel Demodulation (DEMON) recorder
2) 4-channel BSM Recorder

Lower Panel

1) DEMON Controls
   a) ON pushbutton
   b) Internal Marker Pushbutton
   c) Gain adjustment knobs for each of 4 channels
   d) Knob for control of bearing
   e) Selector switches for paper speed, scan rate, D/E system (sonar hydrophones), local/ID slave, and auto/man search

2) BSM Controls

   a) ON pushbutton

   b) Internal marker pushbutton

   c) Gain adjustment knobs for each of 4 channels

   d) Rotary selector switch for frequency band-width control

   e) Knob for control of bearing

   f) Selector switches for paper speed, scan rate, D/E, system (sonar hydrophones), local/ID slave, and auto/man search

3) Noise Compare Controls

   a) Compare on pushbuttons, for audio and recorder comparison

   b) Auto/manual selection pushbuttons for recorder compare and for audio compare

   c) Pushbuttons for controlling source of noise, either raw or stored

   d) Knob for adjusting gain

   e) Rotary switch for selecting channel

   f) Switch for selecting place of presentation: DEMON, BSM or both

4) Controls for Tape Recorder

   a) Channel selector switch

   b) Audio sonar system input selection switch

   c) Tape indicator

   d) Pushbuttons for selecting "on," "play-back," "record," and "rewind."

5) Phone Jacks

4.10.2 <u>Operation of Frequency Monitoring Station</u>

The operator, through frequent monitoring, may detect a signal on any of the recorders located at the Frequency Monitoring Station, so named because the two major displays (DEMON and BSM) have frequency and time as their coordinates. The other display (upper panel), from which a signal may also be detected, has bearing and time as its coordinates.

With the Bearing Time Recorder, the operator is provided with controls for selecting integration time and D/E angle to be searched. The operator can observe the development of a trace (which confirms the presence of a signal) on either the Bearing Time Recorder or the frequency versus time displays on the middle panel. The frequency spectrum of the noise source is presented on the upper display. This recorder scans through 360° in bearing automatically, if it is under local, automatic control. The particular bearing being investigated at a given time is indicated by the fourth channel of the recorder. Each of the other three channels presents one band of frequency data. If he wishes, the operator may position his cursor over one particular bearing, select a D/E angle, and thus initiate the examination of the frequency spectrum at that particular beam. Provision is also made for control at the Initial Detection display. If I.D. slave is in effect, frequency data from the contact at which the I.D. bearing cursor is aligned will be presented on the BSM and/or DEMON recorders.

The displays may also be used for a visual comparison of raw data suspected to contain a signal and stored data which is known to be signal-free. The noise compare controls provide either automatic (pre-set rate of alternation between raw and stored data) or manual selection of presentation rate. By operating pushbuttons the operator may prolong the presentation of raw or stored data to whatever extent he wishes. Stored data are limited to about 24 permutations of environment conditions.

The Band Shift Modulated display provides a narrow band frequency analysis of higher frequency bands. Its operation is similar to that of the DEMON display, although the operator selects the bandwidths to be displayed. The operator may adjust the gain on each of the four channels, and may alter paper speed, scan rate, D/E angle, and source of data.

Also located at the Frequency Monitoring Station are the necessary remote controls for operating the tape recorder for both recording and play-back purposes. This recorder may be used for calibration and checkout functions as well as for reviewing past events.

4.11 CLASSIFICATION STATION (Fig. 4-4)

The total classification phase of the surveillance mission, incorporating both actively and passively collected data, involves aural and/or visual discrimination of many signal characteristics. Such characteristics include frequency distribution, loudness, rate of rhythmic pulsation, target's shape, aspect, motion, and depth. Targets can be classified as friend or foe and as certain types, that is, light craft, warship, cargo.

4.11.1 <u>Controls and Displays at Classification Station</u>

The classification station, which is 36 inches in width, contains the following controls and displays:

<u>Upper Panel</u>

1) Sonar Performance Computer (USN Underwater Sound Laboratory specifications).

2) Classification Recorder Controls

   a) Meter
   b) Pushbuttons for LF In, calibration, normal, and play-back operation
   c) Power supply Alarms - indicator lights for bow, mid, stern, -50 V and -30 V
   d) DC test selector switch
   e) 2-channel selector switches, 1 for channel 1 and 1 for channels 2, 3, and 4
   f) Selector switch for time mark
   g) On, off, standby, and operate pushbuttons
   h) Selector switch for auto/manual scan
   i) Scan rate selector switch
   j) D/E angle selector switch
   k) Rotary knob for controlling bearing
   l) Local/DIMUS slave control selector switch

Middle Panel

1) 4-channel Classification Paper Recorder

Lower Panel

1) Writing and Storage Space

2) Contact Identification Controls

   a) 10 digit classification keyboard with digital readout
   b) Clear keyboard pushbutton
   c) Select contact number pushbutton
   d) Contact data complete pushbutton
   e) Pushbuttons for entering maximum speed, minimum speed, speed error, computed speed, range estimate, port AOB and starboard AOB

   f) Center frequency and band-width pushbuttons

   g) Pushbuttons for identifying: marine life, consort, friendly, enemy, unknown, lightcraft, light warship, heavy warship, light cargo, loaded cargo, surfaced submarine, snorkelling submarine, submerged submarine, diesel, turbine, reciprocating.

4.11.2 Description of Classification Station

There is one major visual display at the classification station. This display does not necessitate the near constant monitoring required at the initial detection or frequency monitoring station. Classification will not be dependent upon the operator's directing a major portion of time to this specific display, but, in contrast, will rely upon his integrating a combination of inputs from various sources. At best, the combination of cues will result in a decision having a high probability of accuracy. The decision will be based upon a comparison of sensed target characteristics and known reference characteristics.

Although "classification" information can be obtained as a result of active pinging, the latter method will be controlled exclusively at the active station. It is assumed that active pinging will seldom be used primarily for classification purposes.

The principal controls and displays provided at the classification station are similar to those previously recommended for the THRESHER (SS(N)593) class submarine. The equipment functions passively to sense and analyze the frequency spectrum of waterborne [illegible] waves. The principal display is the permanent record of the spectrum analysis, provided by electro-sensitive paper. The paper also supplies a record of hydrophone array headings and specific ambient band-width noise levels as a function of time. The noise level indication aids the establishment of detectability threshold and classification validity.

Target classification is accomplished by comparing the recorded spectrum analysis to data from a "library" of target characteristics. Classification is further aided by the presence of audio displays (head-phones) which supply indications of loudness, pulsation rate, etc.

Basic classification information with proper target identity number may be relayed to the tracking stations. If the sonar supervisor initiates classification proceedings, the operator selects the initial detection (DIMUS) position of the slave selector switch. His equipment then automatically processes signal data on the bearing of the contact established at the initial detection station. The correct bearing is that at which the video cursor on the Initial Detection display is located. The classification or frequency monitoring operator may, however, exercise local control over the bearing to be investigated by positioning the switch to "local."

When the operator wishes to transmit information on the characteristics of a target, he selects the contact number via the keyboard and depresses the "select contact number" pushbutton. He then depresses the buttons appropriate for whatever data he wishes to insert. When he completes his entry of information, he again selects the contact number from the keyboard and depresses the "contact data complete" pushbutton to terminate inputs for the particular contact.

Also included at the classification station is the capability for making and playing back tape re ordings.

The classification station contains the SONAR PERFORMANCE COMPUTER, developed by the USN Underwater Sound Laboratory. Own chip noise level and cavitation indications, as well as sonar figure-of-merit, are outputs of the computer.

4.12 LOCALIZATION AND TRACKING STATIONS (Fig. 4-5)
Localization of a target is a process leading to a precise determination of a target's present position: the target's distance from the detecting ship, his spatial direction (bearing), and his depth. The process, moreover, provides additional information from which a target's future location can be predicted.

The station directly at the left of the initial detection station has been designed for accomplishing the function of passive localization and tracking. The station has the capability, however, for active operation if necessary. This station will be the primary station in use under normal watch-standing conditions. This station is 30 inches in width and is located a 45° angle with reference to the initial detection station.

4.12.1 <u>Controls and Displays at Localization and Tracking Station</u>
The following controls and displays are locatod on the several panels of the passive localization station.

<u>Upper Panel</u>

1) 6-inch x 8-inch auxiliary CRT for manual passive ranging; can be function-shared for active range and range rate analysis, and SSI presentation; function selector switch

2) CRT control knobs for adjusting focus, gain, intensity and scale illumination

3) Bearing and D/E pushbuttons for use with SSI

4) Signal Level Meter and sum/diff selector switch

Middle Panel

1) Digital readouts of target number, bearing, D/E, range, and range rate for the compensators

2) Major CRT for passive tracking (function-shared for passive range, active track, passive detection) and scope function selector switch

3) CRT control knobs (same as those in 2) above

4) RLI-UDI Sensitivity Pushbutton

5) Compensator and symbology pushbuttons for active, passive, ATF, and GTT operation

6) BTR indicator light

7) Passive range pushbutton

8) Store pushbutton

9) Relative and unstabilized indicator lights

10) Displayed data selector switch (all tracks, refined tracks)

11) Readout and mark pushbuttons for bearing, D/E, range rate, and range (manual and automatic)

Lower Panel

1) Track ball

2) Track controls: Enter Track and Erase Track pushbuttons

3) Audio Controls

   a) Center frequency selector switch
   b) Band width selector switch
   c) Audio attenuation knob
   d) ICS gain knob
   e) Local/computer 1/computer 2 audio frequency selector switch

4) Phone Jacks

5) Passive Ranging Controls

a) Main scope: knobs for controlling horizontal gain, horizontal position, vertical gain, vertical position, trace separation

b) Upper scope: knobs for controlling vertical gain A, vertical gain B, vertical separation, vertical centering, sweep length

c) Pushbuttons to select upper or lower sweep for track ball control

d) Port and starboard selection pushbuttons

4.12.2 Operation of Passive Tracking Station

It will be recalled that upon selection of GTT at the initial detection station, a symbol, representing the target, can be automatically entered on the passive localization station display.

The main display upon which target data are entered consists of a C scope, bearing, and D/E represented by the x and y axes, respectively. The signal, identified by its sequential number, is displayed as a cross (+) when being tracked grossly at the initial detection display. To proceed with precise localization and tracking the operator must "lock-on" to the target provided by the initial detection station. He accomplishes this procedure by (1) depressing the appropriate compensator selector pushbutton, (2) positioning a ring representing the compensator around the cross, and (3) depressing the enter track pushbutton. (The cross is replaced by a dot when tracking is assumed by the spherical system.)

It is assumed that tracking will require the training of one of three mechanical compensators on the target. The display provides a means to enable the operator to sense any deviation of the compensator position from that of the maximum signal. The operator nulls any

deviation by using a track ball, centered in the lower panel to position the ring which represents the compensator around the dot which incorporates BDI/UDI information.

When any bearing and/or D/E error between the compensator and the target has been nulled, the operator may push "Read out" pushbuttons for a digital readout of bearing and D/E. The digital readouts, located above the display, also provide the identification of the compensator (1, 2, or 3) with which a given target is being tracked. Each set of readouts should be color-coded for maximum differentiation. If, after the nulling of deviations, Automatic Target Following (ATF) is initiated, continuous digital readouts of bearing and D/E will be displayed and marked to Fire Control.

It is possible to obtain continuous readouts when tracking is being accomplished manually by "locking" the desired readout button into place.

If generated target tracking is available, it can be initiated by activating a back-lighted pushbutton located in the control matrix. The activation of the selected mode pushbutton also results in the generation of a symbol on the display which designates the particular mode.

The compensator and mode selector controls are located at the right of the main display at the passive station.

The system should be capable of generating codes representing the target's sequential identification, gross classification (friend, foe, or unknown), and source of bearing and D/E or, in active transmission, range information. Specifically, the compensator involved and the source or mode (ATF, GTT, or manual) in which the compensator is operating should be indicated. It is recommended that compensator identification be color-coded to be consistent with the coding of the digital readouts. The exact nature of additional symbology appropriate for employment in the system has not be determined at this time. The recommendations of a combination of symbols that can be optimally utilized by the operator should be based on the results of a separate study of the problem.

The passive tracking operator as well as the initial detection operator has the capability for erasing a target.

Customary CRT controls (for intensity, focus, and gain) are located at the left of the passive tracking display as they are in the initial detection display.

The third target parameter which can be established at the passive tracking station is range. It has been assumed, for the purposes of the study, that passive ranging will be an essentially automatic operation and that the principal display for the operator will be a digital readout. By function sharing the passive tracking with the passive ranging display, the operator will have available a CRT on which he can perform the only manual task required in the basically automated system. Under normal conditions of passive ranging, the operator performs a "global inspection" of correlograms on the main scope. The operator utilizes his scope selector switch to initiate passive ranging operation. Correlograms, which must be gated manually, appear on the lower quarter of the main display. The operator gates the bearing sector containing the selected signals by selecting and positioning the track ball, after having depressed the passive ranging enter and the upper or lower sweep pushbuttons. Precise correlogram matching (or alignment), which will determine the range, is performed by the computer after the operator depresses the "enter track" pushbutton, and the results are presented as digital readouts, which can be transmitted to Fire Control The readout displays are presented directly above the passive tracking scope.

If manual passive ranging is required, the small (6-inch x 8-inch) CRT, located directly above the principal passive tracking station, is employed. The small CRT is function-shared and may be used for manual passive ranging as well as for other functions described elsewhere. The operator, in the manual mode, performs rough gating on the main display, but fine alignment of correlograms is done on the small CRT. The handwheels necessary for fine alignment are recessed and covered during normal, automatic operation.

A scope selector switch at the lower right of the small scope permits the operator to choose the particular function he wishes to accomplish on the small scope.

Other controls necessary for manual passive ranging are located at the right of the track ball on the lower panel. Should it ever be necessary to perform manual passive ranging on two targets simultaneously, the upper panel display scope at the far left station could be also used for fine correlogram alignment. In this way one major CRT would be reserved for passive tracking.

It should be noted that passive detection, utilizing spherical inputs, can be controlled at this station. In an emergency situation, or a situation in which it is desirable to use the spherical array rather than DIMUS for initial detection purposes, signals can be displayed on the main scope after the scope selector switch has been placed in the passive detection position. The track ball then controls a bearing cursor and bearing is presented on the x-axis with amplitude on the y-axis.

4.13 ACTIVE TRACKING STATION

The station at the far left (44 inches in width) serves the principal function of active localization and tracking, although, it should be noted, it also serves to augment the passive tracking and ranging capability through function sharing. The assumption of increased automation in passive ranging, active range rate analysis, and sonar communication has permitted recommendations for considerable control and display consolidation.

4.13.1 Controls and Display at Active Tracking Station

The active tracking station contains the following controls and displays:

Upper Panel

1) Sonar communications card reader

2) Sonar communications recorder

3) Sonar communications recorder "on" pushbutton

4) Sonar communications recorder contrast control knob

5) CRT for passive ranging, SSI presentation, range rate analysis, sonar communications

6) CRT function selector switch

7) CRT control knobs for focus, intensity, scale illumination, gain, and bearing and D/E selector pushbuttons

8) Signal level meter and sum/vertical difference/horizontal difference selector switch

9) Speaker

10) Sweep rate selector switch

11) Pushbuttons for sweep delay, standby, operate

12) Indicator lights for stored and channel (1, 2, or 3)

13) Pushbuttons for display and channel (1, 2, or 3)

14) Tape recorder controls

a) Tape indicator
b) Pushbuttons for on, playback, record, rewind
c) Rotary switches for selecting channel and selecting sonar system

<u>Middle Panel</u>

1) Oven indicator light and Reset pushbutton

2) Pushbuttons for Increase, Decrease, Mark, and Reset

3) Vernier adjustment knob

4) Range rate set knob

5) Pushbuttons for alarm reset, message ready, operate, test, gate on normal, voice, and receive only

6) Indicator lights for standby, transmitter ready, SESCO, and computer ready

7) Selector switch for transmitter equalize

8) Pushbuttons for send message, time enter, bearing, decode, stop

9) Digital readout display

10) Digital readouts of target number, bearing, D/E angle, range, and range rate for compensators 1, 2, and 3

11) Relative (bearing) and unstabilized indicator lights

12) Major 9 x 12 CRT principally for active tracking. Also used as back-up for passive tracking, passive ranging, and passive detection.

13) CRT control knobs, same as 7 on upper panel

14) Scope function selector switch

15) Readout and mark pushbuttons for bearing, D/E, range rate, automatic range, manual range

16) Displayed data selector switch for all-target or refined track display

17) STORE pushbutton

18) Compensator and symbology pushbuttons for active, passive, ATF, or GTT operation.

19) BTR indicator light

20) Passive range pushbutton

21) Selector switches for dwell time, pulse length, selected range, power, speed, and beam width

22) Indicator lights for manual speed input and reduced power

23) Pushbuttons for on, standby, ready, single ping, continuous ping, stop

24) RLI/UDI sensitivity pushbutton

25) Tri-beam bearing rotary selector switch

26) Sonar communications time, range, and range rate digital readouts.

Lower Panel

1) Sonar communications keyboard

2) Sonar communications readout

3) Selector switches for center frequency and band-width

4) Knobs for adjusting audio attenuation and ICS gain

5) Selector switch for local or computer control of audio frequency

6) Track ball

7) Pushbuttons for Enter Track and Erase Track

8) Phone jacks

9) Passive Ranging Controls

a) Main scope: knobs for controlling horizontal gain, horizontal position, vertical gain, vertical position, track separation

b) Upper scope: knobs for controlling vertical gain A; vertical gain B, vertical separation, vertical centering, and sweep length

c) Pushbottons to select upper or lower sweep for track ball control

d) Port and starboard selection pushbuttons

e) System controls: integration sensitivity, integration time, sweep length, and shaping

4.13.2 Operation of Active Tracking Station

The main scope at the active station is used as a C scope during the passive ("Listen") operation of the active station and a B scope during active operation. When active pinging is desired, the smaller CRT on the upper panel directly above the principal CRT is utilized for display of the return echo from a selected sector determined by the position of the tracking compensator. During the passive mode, the operator uses the track ball to null deviation between the target

and the compensator for the establishment of bearing and D/E in a manner identical to that used at the passive station. To provide consistency among signal symbols, the solid dot and the ring have been maintained for representation of the target and compensator, respectively.

The major active controls are located at the right of the active station in the center panel. They are also accessible to the operator at the passive station. By positioning the rotary selector switches for beam width, the operator may choose the beam width he wishes in active pinging. Pushbuttons are provided for the selection of single or continuous ping.

If, using the scope selector switch, the operator chooses the active sonar mode of operation (B scope), a range scale on the y-axis of the scope is automatically lighted and is used instead of the D/E scale that is used during the passive mode (C scope). A vertical and a horizontal cursor are used for tracking in bearing and D/E or range respectively.

Digital readouts for bearings, D/E, range, and range rate as well as compensator identification are provided directly above the main display on the center panel. At the right of principal active station controls are located the compensator and scope symbology controls. Compensator mode, i.e., manual, ATF, and GTT, pushbuttons are provided here.

Their activation is associated with the appearance of symbols on the CRT to designate selected modes.

When the scope on the upper panel at the active station displays a sector (SSI), the scopes at both active and passive stations, through function-sharing, can be used to display range vs bearing also. While precise bearing and range are being determined at the active station, other contacts or noise sources can be displayed and observed simultaneously.

It has been assumed that the analysis of range rate will be performed automatically as directed by the operator. The operator has the capability of storing a segment of the received signal for analysis and subsequent playing back during an analysis mode. In the automated system, the operator ultimately will be concerned only with the digital readout of range rate. The present design, however, incorporates all controls and displays necessary for manual back-up. If range rate analysis is to be performed manually by the operator, it is accomplished by measuring the difference between the transmitted signal frequency and the returned signal frequency. In the manual mode, one of the CRT's located on the upper panel would be utilized by the operator. Lines of variable slope would be displayed on the CRT. To obtain range rate the operator must eliminate the slope of the lines through adjusting the associated handwheels (recessed below the lower panel) in a manner similar to that presently employed in the BQQ-1 system. The required frequency change is the measure of range rate.

In the envisioned automated system, however, it will be only necessary for the operator to initiate the storage of increments of received information at selected ranges. Precise range and range rate data can be displayed on digital readouts and can be transmitted to Fire Control by activating the associated readout/mark pushbutton.

Controls for active communication through SESCO have been placed at the left of the center display at the active station. If SESCO is to be operated from the surveillance console, the location represents an optimal choice since SESCO derived information is used directly by Fire Control. It should be noted, however, that communications has not been assumed to be a primary responsibility of the surveillance mission per se and that the repositioning of all controls and displays, except those directly related to active transmission of target location data, should be considered. The required evaluation of the optimal location is beyond the scope of the present study.

The SESCO card reader and recorder have been placed on the top panel. Function-sharing of the main scope located on the upper panel (left) will provide a CRT for SESCO reception and transmission. Although it has been recommended that the frequency shift keying control for encoding be done on magnetic tape, the manual keyboard has been retained for back-up purposes. While specific controls and displays have not undergone any essential alteration, the entire system has been consolidated into one functional grouping to facilitate operation.

4.14 Contact Status Display (Fig. 4-4)

This alpha-numeric unit, located on the header panel at the fire control - surveillance junction, is used for evaluations and decisions by the fire control and command stations based on contact identification and classification by surveillance.

The display shows the tracking sensor and classification status for every contact currently under detection. The tracking sensor and contact number is displayed upon assignment of a number of a new contact. A contact, once detected, is designated by the same number even though it may be shifted to a sensor other than the initial detecting one. The classification parameters of threat, vessel type, and vessel condition are initiated by the surveillance classification keyboard.

The fire control party may use the displayed information to evaluate speed solutions obtained for a particular target. This evaluation would be based on the vessel type and condition classification. The command station may use the display as a means of knowing when sensors are displayed and which are unassigned or available for reassignment. Based on the threat classification, command can evaluate the urgency associated with a particular contact.

V

FIRE CONTROL

5.1 INTRODUCTION

It is evident that if the SUBIC objective of increased effectiveness of the several systems under consideration is to be met, then the role of the human component, as well as the machine, must be enhanced.

Current fire control tactics manuals (Ref. 1, 2) do not explicitly state all the functions and tasks performed by humans in fire control systems. The decisions and control actions generally present are hidden among the mass of equations and plotting procedures described for solving the particular problems. Thus some form of analysis must be undertaken to manifest these equally important human tasks.

This section, accordingly, represents an analysis of submarine fire control systems to ascertain the functions and tasks of both men and machines involved in the generic fire control problem. This study likewise provides the basis for the allocation of tasks, either to man or machine, for the design of a 1965 THRESHER class submarine fire control console.

The report is divided into several sections: the methodology for the analysis, the results of the analysis (including man-machine allocation), special considerations of the designed console, and an operational description of the console.

5.2 METHODOLOGY

This section presents the methodology employed in analyzing the fire control area and thereby provides a basis for subsequent design of a fire control console. A statement of the methodology is relevant at this point in order to show the criteria by which the study was guided.

5.2.1 Generic Mission

The first step in the program was the derivation of a mission, including system objectives, of the generalized fire control system. In relation

to the mission and to provide ground rules for the remainder of the study, the working assumptions (for example, vessel activities), system constraints (for example, weapons considered), and definitions were stated.

5.2.2 Determination of Functions and Task Analysis

Continuing on the mission in 5.2.1 above, the functions accomplished in the weapons system were delineated. A function is defined as an action or performance which contributes toward obtaining the system objectives.

In turn, each stated function was analyzed and classified in terms of the tasks which accomplish a specific function. The categories for task classification are the following:

1) Decision tasks involving coordination of information and/or tactical alternatives.

a) situation decision. Conclude a certain state exists from a number of possible alternatives.

b) action decision. Select a course of action from a number of alternatives.

2) Operator tasks involving button-pushing or error-nulling operations.

3) Computational tasks involving mathematical manipulations.

This classifying of tasks also serves as a means of categorizing functions to facilitate further assignment to a decision-maker or button-pusher.

5.2.3 Allocation of Functions to Man and Machine

From the above analysis, each of the functions was allocated depending upon whether it was best handled by human or machine capabilities. The general criteria for assignment were based on the relative capabilities of man and machines as specified by Fitts (Ref. 3).

It is apparent that the decision for function allocation is highly dependent on the technological state-of-the-art. In this study allocation is assumed permissable on reasonably projected state-of-the-art in digital computer technology.

5.2.4 Information Requirements

For those tasks clearly dependent on man's capabilities and for those of which the allocation is uncertain, the information requirements (defined as data necessary for task accomplishment) were determined and then classified in terms of their relevant characteristics. Information classification by characteristics, plus the preceding classifications, provide basis for logical console design by way of distinguishing pertinent information, information groups, and priority assignment.

The categories are as follows:

1) Source
   - a) enemy
   - b) environment
   - c) own ship
   - d) consort
2) Temporal aspect
   - a) long term history - provide books, charts, etc.
   - b) short term history - computer storage
   - c) present status - computer storage
   - d) projected status - trial situation displays or quickening
3) Criticality - indicators of criticality
   - a) signal changes during missior
   - b) other aspects of operation dependent on this signal
   - c) correlation between a given amount of signal change and change in probability of mission success
4) Accuracy - indicates amount of error to be displayed

5) Precision - determines fineness of display scale

6) Relationship of information items. Must an item be displayed with another item to be meaningful? Is it to be compared?

5.2.5 Preliminary Console Design

Based on the preceding four sections, a preliminary tactical weapons console was designed. Since current state-of-the-art was not considered a limiting factor at this level, extrapolations to feasible equipment capabilities has to be made if an optimum-approaching design is to be realized. Inference was based on projected present technology, but uncertain aspects were submitted to knowledgeable persons in computer technology and human factors sections.

5.2.6 Preliminary Mission Analysis Evaluation

The preliminary designed console from Section V was evaluated in terms of ability to carry out necessary operations and complete missions as defined by the fire control mission and functional analysis presented in the earlier stages of the study.

5.2.7 Final Console Design

In view of incompatible and neglected displays and controls, as shown by the evaluation, and in terms of computer and technological limitations, a final console design was refined from the preliminary sketch.

In summary, essentially a deductive method was employed: if task A must be performed, then information items 1, 2, and 3 are required. The method contains one inherent disadvantage of not providing knowledge of omissions; therefore, the analyst's awareness of the various facets of fire control operations is the limiting condition. In this regard, the study gains strength only by constant reiteration and a conclusive solution will be provided only by experimental testing of the tasks and information requirements listed.

The publications consulted, besides those already cited, are presented in the general references at the end of this chapter.

5.3 ANALYSIS

This section represents the analysis of the submarine fire control system to ascertain functions and tasks, their subsequent allocation to man or machine, and the determination of the required information to accomplish these tasks.

5.3.1 Definitions

1) Fire control system: the combination of activities which utilizes the sensed inputs from the several surveillance systems to localize targets in the environment and compute directions to guide weapons to those targets.

2) Target localization or definition: that phase of fire control concerned with specifying the target's position based on sensed inputs or estimates from surveillance.

3) Weapon direction or control: that phase of fire control dealing with the preparation and guidance of tactical weapons.

5.3.2 Assumptions and Constraints

The following assumptions and constraints provide the general ground rules for the study.

5.3.2.1 Assumptions

1) The primary mission of the submarine is to conduct anti-submarine warfare and destroy targets of opportunity. The contingent missions listed below are excluded from consideration at this time.

a) Mining

b) Reconnaissance

c) Lifeguard

d) Radar picket

e) Special landing operations

f) Strategic weapon operations

2) Torpedo room aspects of weapon control were not considered unless they reflected back on control room weapon operations.

3) A central digital computer is available for fire control purposes.

5.3.2.2 Constraints

1) Submarine stealth must not be compromised unless the initiative remains with the friendly forces.

2) Weapon input requirements are inviolate.

3) Only the following weapons will be considered as available for future tactical deployment in console development:

MK 16 Mod 6 - preset, straight-runner
MK 37 Mod 0 - preset, homing
MK 37 Mod 1 - preset or wire-guide
MK 45 Mod 0 - preset or wire-guide
EX-10 (RETORC II) - preset or wire-guide
EX-3 (SUBROC) - submarine rocket

At present, neither the mathematical model nor the control circuits for the EX-10 are completely defined; therefore, the controls and displays for this weapon, incorporated in this study, will be those listed as necessary in a Hughes Aircraft Company memorandum to Electric Boat Division, dated 24 August 1961.

The torpedoes MK 28 Mod 0 and MK 27 Mod 4 are deleted on the basis of replacement by the MK 37 Mod 0 as stated in "SUBLANT Information Bulletin," January 1960.

The MK 14 Mod 5 torpedo is omitted since it is no longer in production and few remain within the submarine force.

5.3.3 <u>Fire Control System Mission</u>

The objective of a fire control system is localization of a target's present position through determination of target motion parameters based on sensor inputs concerning own ship and target. From the target's present location a future position is extrapolated, for which an approach tactic and a weapon are selected which maximize the probability

of kill. Then the correct weapon geometry must be determined to ensure weapon and target coincidence at a specified time after firing.

The fire control system mission may be regarded as a phase of the total submarine mission and, in turn, each component operation of the fire control system may be regarded as a phase of the fire control mission. In the following fire control functional analysis the system mission is partitioned into separate operating phases to enhance classification and clarity. This partitioning does not assume phase independence or strict time sequence. In fact, functions of one phase may be accomplished prior to completion of a preceding phase.

Each phase of the mission may be classified as to its phase function but within each phase are listed a number of subfunctions which are necessary for accomplishment of the particular phase function.

For each of the listed functions the tasks necessary for accomplishment have been derived and then classified in terms of the characteristic operation involved. This categorization serves to differentiate the tasks and provide the basis for subsequent man or machine allocation.

The categories of classification are as follows:

A) Decision tasks involving coordination of information and/or tactical alternatives, including:

a) situation decision: conclude a certain state exists from a number of possible alternatives.

b) action decision: select a course of action from a number of alternatives.

B) Operator tasks involving button-pushing or error-nulling operations.

C) Computational tasks involving mathematical manipulations.

Task classification is indicated by letter designation to the left of each task.

5.3.4 Functional Analysis

Phase Function - Target Localization

Function: Designation of contacts for motion analysis.

A2 Tasks: 1) Decide which contacts are to be analyzed.

2) Order fire control system to provide localization solution for a specific target.

Function: Selection of localization mode.

A2 Tasks: 1) Decide on solution mode to localize target.

B 2) Order system to utilize selected mode.

Function: Selection of sensors for data inputs to localization problem.

A2 Tasks: 1) Decide which sensor will provide optimizing inputs.

B 2) Order systems to utilize selected sensor inputs.

Function: Localization of target relative to own ship

C Task: 1) Solve geometry for target position relative to own ship; specifically, determine range, speed, depth, and course.

Subfunction: Bearing correction and stabilization for data processing.

C Task: 1) Reject spurious bearings and add correction factors pertaining to sound-in-water phenomena.

Subfunction: Direction of target motion determinations.

C Task: 1) Ascertain direction of bearing drift

	Subfunction:	Determine if target is opening or closing
C	Task:	1) compute relative angle-on-the-bow.
	Subfunctions:	Determine own ship maneuvers to facilitate localization solution.
A2	Tasks:	1) Decide on own ship maneuver
A2		2) Determine time to execute own ship maneuver.
	Subfunction:	Target maneuver detection (include type of maneuver)
C	Tasks:	1) Test significance of predicted target path against derived path.
C		2) Project new target path backwards to determine time new path differed from predicted path.
	Subfunction:	Determine probable time and type of next target maneuver.
C	Tasks:	1) Compute representative maneuver time and probability of any type maneuver.
	Function:	Utilization of target parameter estimates.
A1	Tasks:	1) Decide whether to utilize estimates.
B		2) Order system to utilize estimates.
	Function:	Own ship maneuver for Type III localization solution (See localization chart)
A2	Task:	1) Decide when and how to make own ship zig in a Type III localization solution.
	Function:	Evaluation of localization solution.

Phase Function - Approach Tactic Determination

A1 Tasks: 1) Determine whether target range is greater than weapon range.

A2 2) Decide on an approach tactic to close target.

C 3) Solve geometry for approach course, speed, and depth for own ship under constraints of any one or combination of the following:

a) arrival time

b) range

c) torpedo track angle

d) gyro angle

e) firing bearing

Phase Function - Weapon Selection

C Tasks: 1) Determine the kill probability for each type of weapon and spreads of weapons.

A2 2) Select a weapon(s) which will maximize the probability of killing the target.

B 3) Order system to utilize the selected weapon.

Phase Function - Determination of Weapon Geometry

C Task: 1) Solve geometry for:

a) gyro angle

b) running depth

c) running speed

d) enabling run, run-to-burst

e) missile trajectory

f) thrust cutoff velocity

C 2) Determine

a) firing bearing

b) spread interval

c) firing interval

d) firing time.

Phase Function - Weapon and Tube Preparation

B	Tasks:	1)	Assign target to weapon
B		2)	Assign weapon to tube
B		3)	Order steps in weapon preparation
B		4)	Order steps in tube preparation
B		5)	Check weapon acceptance of weapon functions
B		6)	Monitor steps in weapon and tube preparation and monitor weapon warnings (limits and malfunctions).
B, C		7)	Assign firing order and check acceptance
B		8)	Order wire-guided torpedo to be guided in a specific mode.
B		9)	Order weapon to be fired in a specific mode.

Phase Function - Weapon Firing

C	Tasks:	1)	Decide when to fire.
A2		2)	Decide what actions can be undertaken to improve probability of target kill; that is, fire now or perform some intermediate action.
B		3)	Order weapon to be fired.
B		4)	Check weapon response to fire.

Phase Function - Post-Firing Weapon Guidance (Wire-guides)

C Tasks: 1) Solve geometry for present weapon position relative to target and determine error between target and weapon paths at incidence point.

C 2) Reduce error in target and weapon paths to ensure coincidence at impact point.

5.3.5 Allocation of Tasks

The primary purpose of task allocation within a system is to maximize the over-all system effectiveness in terms of the system objectives. Man and machines differ relatively in their capacity to provide the degree of a specific capability demanded by a task. Optimum task accomplishment warrants, therefore, that this relative difference be exploited by employing the system component which supplies a particular capability best.

As stated previously, to obtain a meaningful task assignment it is first requisite to analyze each task to determine the capabilities necessary for accomplishment. Allocation then proceeds by approximating matches of the abilities of the man and/or the machine with those required.

In the preceding phase of the study each task was classified in terms of task type. This resulted in three major classes which are analyzed and assigned by the following reasoning.

5.3.5.1 Decision Tasks

A decision, by definition, demands the ability to choose between a set of alternative states or actions. The tasks classified as decisions have the common characteristic that this "choosing" is dependent upon a number of inputs or information requirements. This characteristic implies (1) some relation (not necessarily constant) exists between these inputs and (2) this relationship must be perceived correctly in order to choose an appropriate alternative.

Fitts and others have suggested that the decision-making process is best suited to human capabilities for at least the following reasons:

1) Ability to select own inputs

2) Ability to profit from experience

3) Ability to handle unexpected events without previous experience or programming.

In this study the decision tasks have been allocated to the man, but further inspection may prove rewarding.

The key to man's relative ability to make decisions seems to lie with the problem of the relationship between information requirements and, because of this, decision-making is often awarded to man by default.

In the realm of tasks commonly classified as "decisions" (choosing between alternative situations or actions) the tasks are characterized by a number of inputs which must be coordinated and weighed before the choice can be made. But the relationship between these inputs is often unknown. Man does utilize these inputs or information requirements in some relationship and he does make decisions as a result. The nature of the relationship, however, is often unknown to the man himself even though it is utilized.

When researchers state that man is better than the machine at decision-making for some given reason (that is, ability to profit from experience), the case is merely being stated that the man does have some method of coordinating and evaluating the inputs. In fact this ability to utilize these inputs is based on a considerable history of trial and error situations where first one combination of inputs and then another have been employed to arrive at a successful decision.

Heretofore, science has not discovered the relations existing between information requirements for decisioning, which in turn precludes machine programming. In addition, only a beginning has been made in understanding how to enable machines to modify their own behavior (profit from experience).

In summary, the man is assigned decision-making tasks not necessarily upon his final superior ability, but merely because he does utilize the available inputs (correctly, is another question) in some relationship to solve his problems. The optimum allocation must await a better understanding of the decision-making process.

5.3.5.2 Operator Tasks

The class of tasks designated as "operator tasks" are allocated to the man in that their accomplishment serves as a transmission link between the decision-maker (man) and the machine. At those points where the system is ordered to carry out some action the operator serves to program the machine on the basis of a decision. Thus, the operator serves as the communication line from the decision-maker to the machine. In those cases where the operator task demands monitoring of the system (warning and weapon preparation monitoring), the operator serves as a link from the machine to the decision-maker.

5.3.5.3 Computational Tasks

Computational tasks are mathematical manipulatory tasks demanding information processing by logical rules. Contrary to decision tasks, the exact relations between inputs are well known (geometric and statistical analysis), the inputs are amenable to quantification, and the programs are readily specified. Thus, these tasks are allocated to the machines, since machines are superior to man in exact computation and in utilizing logical rules at high speed for information processing.

5.3.6 Information Requirements

For those tasks which were allocated to the man in the preceding section, the information requirements deemed necessary for accomplishing the tasks are listed below (Table 5-1). Subsequently, each information requirement has been classified by pertinent characteristics and tabulated. The purpose of classification by characteristics is to provide a basis for display relevance: should the information be displayed, how it is to be displayed, how it is to be displayed in relation to other information, and what is the logical grouping of information for

display. This, in turn, will result in display concepts which can be utilized in the final fire control console design.

The categories of classification are the following:

1) Object referent: provides information grouping

a) enemy

b) environment

c) own ship

d) consort

2) Temporal aspect: determine type of display

a) long term history: provide books, charts, etc.

b) short term history: computer storage, immediate console displays

c) present status: computer storage, immediate console display

d) projected status: provide trial situation displays or quickening.

3) Criticality: if an item of information has a criticality index, it should be displayed.

a) signal changes during mission

b) other aspects of operation dependent on this signal

c) correlation between a given amount of signal change and change in probability of mission success.

4) Relationship of information items: indicates whether items of information must be displayed, compared, and/or integrated with other items to be meaningful.

Information requirements could be classified by at least two other categories. These are "accuracy" and "precision." Accuracy of information is concerned with the reliability of the sensor; precision with

the fineness of dial display. In this study, which is an analysis of the generalized submarine fire control system, consideration of these categories is not warranted.

A sensor certainly should be as accurate as possible, but the degrees of accuracy for which sensor designers should strive can only be determined by the allowable error within a system. In the case of fire control, this will be determined by the solution error allowable for a test of significance.

Precision can be determined only for a specific system: if a particular torpedo has fixed units of 2 degrees for course change, no advantage is gained by incorporating dial readouts with 0.1 degree gradations. This study has not gone into detail in considering existing or proposed systems to an extent that would allow such specification of displays.

5.4 SPECIAL CONSIDERATIONS

This section discusses changes incorporated in the proposed fire control console which are special in regard to existing fire control systems. The assumption underlying these changes is the utilization of a central high-speed digital computer by the submarine fire control system.

5.4.1 Emergency Operation

In the proposed system the emergency mode consists of the use of a manual plotting table (for example, the Mk 19 Plotter) and a torpedo control unit located in the torpedo room. No failure of a specific fire control function (target analysis, position keeping, weapon direction) is conceived without a total computer failure. That is, since the computational elements are of the digital type, no specific portion of the computer is assigned a specific function. If portions of the computer fail, it is assumed priority programming will allow continuing calculation of the fire control problem. It is reasonable that degraded outputs may result from loss of partial computer capacity, but total loss of a specific function *per se* will not occur. In case of

TABLE 5-1
INFORMATION REQUIREMENTS ANALYSIS

Information Requirements	Object Referent	Temporal Aspect	Criticality	Relationship	Display and Control Comments
TARGET LOCALIZATION PHASE					
I Decide which contact to analyze					
A) Classification	enemy	present	a, b	1, 2 together form basis for evaluating threat.	These are threat classifications; should be available to C.O.
friendly enemy consort unknown					
B) Initial contact data available	enemy	present			a, b, c must be displayed for monitoring
bearing			a, b		
bearing rate			a,b,c	b,c can indicate target's range	
bearing acceleration			a,b,c		
speed			a,b,c		
range			a,b		
II Order system to provide localization solution for a specific contact					Provide controls for programming system.
Contact designated for analysis	enemy	present			
III Decide on solution mode to localize target.					
A) Solution modes available	enemy	present	b		Solution modes do not change; modes are explained in books.
single absolute range maximum range complete solution					

TABLE 5-1 (CONT)

Information Requirements	Object Referent	Temporal Aspect	Criti-cality	Relation-ship	Display and Control Comments
TARGET LOCALIZATION PHASE					
III A) Continued					
bearings only bearings plus an estimated or known target parameter					
B) Sensor accuracy and reliability	own ship	long term			2, 3 are known prior to mission. Books are adequate
C) Solution accuracy	own ship	long term			
D) Solution speed	own ship	long term			4 varies as a function of available data; not specifiable until solution is started.
E) Time available for solution		present			
F) Sensors available	own ship	present	a,b		
IV Order system to utilize selected solution mode					
Mode selected		present	a,b		Provide controls to program systems for those solution modes requiring particular manipulation of the data.
V Decide which sensor(s) will provide optimum inputs for localization					
A) Solution mode decided upon	own ship	present	a		

TABLE 5-1 (CONT)

Information Requirements	Object Referent	Temporal Aspect	Criti-cality	Relation-ship	Display and Control Comments
TARGET LOCALIZATION PHASE					
V B) Sensors available within that mode	own ship	present	a,b		Sensor inputs underlie the type of solution mode utilized. Thus sensors available should be displayed to enable decision of solution mode.
Single absolute range					
active sensor active sonar radar periscope consort PUFFS range resulting from own ship zig.					
Maximum range					
auditory judgement via passive sonar					
Complete solution - range, course, speed					
two or more absolute ranges active sensor consort PUFFS					
bearings only passive sensor sonar ECM		present	a		
Bearings plus an estimated or known target parameter		present	a		

TABLE 5-1 (CONT)

Information Requirements	Object Referent	Temporal Aspect	Criticality	Relationship	Display and Control Comments
TARGET LOCALIZATION PHASE					
V B) Continued					
passive sonar for the bearings and the estimate					
sensor supplying known target parameter					
active range sonar radar					
passive range sonar periscope consort PUFFS					
C) Sensor accuracy and reliability		long term and present		error associated with a sensor input is meaningful only in terms of that input	If sensor accuracy changes during mission the system must be aware of the degradation effects. Books
VI Order system to employ the selected sensor inputs					
Sensor inputs selected	enemy	present	a,b		Same as II above
VII Decide whether to use estimates of target parameters					

TABLE 5-1 (CONT)

Information Requirements	Object Referent	Temporal Aspect	Criti-cality	Relation-ship	Display and Control Comments
TARGET LOCALIZATION PHASE					
VII A Solution mode being utilized	enemy	present			
B Estimates available	enemy	present	a,b,c		Controls must be provided to program computer in terms of type of estimate (range, course, speed) and value (absolute, maximum, minimum plus numerical input)
passive sonar					
absolute speed from turn count minimum speed maximum speed minimum range maximum range course from angle-on-the-bow					
intelligence data					
course speed range					
C Probable error of estimate	enemy	present	b		Accuracy of solution depends on error term. Controls must be provided to allow entering error term into computer solution.
VIII Order system to utilize estimate					
Estimate selected					Same as II above
numerical value					
absolute maximum minimum					

TABLE 5-1 (CONT)

Information Requirements	Object Referent	Temporal Aspect	Criticality	Relationship	Display and Control Comment
TARGET LOCALIZATION PHASE					
IX Decide when and how to make own ship zig in a type III localization solution. (See localization chart)					
A) Total tracking time on first leg	enemy	short term history	b		
B) Stability of first leg information	enemy	short term history	b		
C) Course and speed which will open target bearing deviation on second leg of own ship maneuver	own ship	projected	a, b	meaningful only in relation to target position	Provide relative position display to indicate how own ship maneuver will open bearing deviation.
X Decide if target is localized with a high probability					
A Target parameters	enemy	present	a, b	2 reflects on accuracy of 1	1 and 2 displayed together
B Error associated with each parameter					
C Source of error				1,2,3,4,5 must be integrated to arrive at a probability figure.	Probability figure of 1,2,3,4,5 should be displayed, if obtainable
sensor	own ship	present	a,b,c		
environment	environment	present	a,b,c		
deception devices	enemy	present	a,b,c		

TABLE 5-1 (CONT)

Information Requirements	Object Referent	Temporal Aspect	Criti-cality	Relation-ship	Display and Control Comment
TARGET LOCALIZATION PHASE					
X D) Amount of target data					
E) Correlation of results of one solution mode with another				Solution modes must be compared.	
APPROACH TACTIC PHASE for target range greater than weapon range					
XI Determine whether target range is greater than weapon range					
A) Target range	enemy	present	a,b	1,2 must be compared	1 must be continually displayed. 2 is available in books.
B) Range of w[illegible]on considered	own ship	present			
XI Decide on an approach tactic to close target					
A) Target position	enemy	present	a,b		1 can be determined from IX, (A).
B) Future target position without target maneuver	enemy	projected	a,b		2 and 3 suggest a predictor display showing range of possible target positions.
C) Future target position under possible target maneuver	enemy	projected	a,b,c		
D) Own ship capabilities	own ship	long term and present	a,b		trial situation display

TABLE 5-1 (CONT)

Information Requirements	Object Referent	Temporal Aspect	Criticality	Relationship	Display and Control Comments
APPROACH ATTACK PHASE					
XI E) Weapon capabilities	own ship	long term	b,c		weapons are available; display books are adequate for known weapon capabilities.
F) Probability of losing target due to own ship maneuver	enemy	projected	a,b,c		6 and 7 probability figure for any maneuver should be shown.
G) Probability of target detecting own ship due to own ship maneuver	enemy	projected	a,b,c		
H) Position of other vessels (present and future)	enemy consort friendly unknown	present and projected	a,b		past, present, future position of all vessels should be displayed (computer storage).
I Environmental limitations	environment	present and projected			warnings of environmental limitations should be displayed.
J Desired position relative to target at end of own ship maneuver	enemy	projected	b	related to 4.	
WEAPON SELECTION PHASE for target range less than weapon range					
XIII Select weapon(s) which maximize the probability of target kill					

TABLE 5-1 (CONT)

Information Requirements	Object Referent	Temporal Aspect	Criticality	Relationship	Display and Control Comments
WEAPON SELECTION PHASE					
XIII A) Weapons available	own ship	present	a,b,c		
B) Weapon kill probability	enemy	present	a,b,c	kill probabilities for different weapons must be compared	display kill probabilities together
straight running homing wire-guided missile spread of weapons					
XIV Order system to employ selected weapon					
Weapon selected	own ship	present	a,b		same as II
WEAPON AND TUBE PREPARATION PHASE					
XV Assign weapon to target					
A Target designation	enemy	present	a,b	1 and 2 meaningful together	weapon and target assignment controls
B) Weapon selected	own ship	present	a,b		
XVI Assign weapon to tube					
A) Weapon selected	own ship	present	a,b	1 and 2 meaningful together	weapon and tube assignment controls
B) Tube selected	own ship	present	a,b		
XVII Order steps in weapon preparation					

TABLE 5-1 (CONT)

Information Requirements	Object Referent	Temporal Aspect	Criticality	Relationship	Display and Control Comments
WEAPON AND TUBE PREPARATION PHASE					
XVII Continued Steps in weapon prep.	own ship	present	a	Follow in sequence	same as II; not an automatic sequence
ready torpedo arm weapon					
XVIII Order tube preparation sequence					
Steps in tube preparation	same as XV				
flood tubes open doors					
XIX Check acceptance of weapon functions					
Weapon functions	own ship	present	a,b,c	Not all functions refer to a particular weapon; thus, applicable ones should be displayed with the relevant weapon	the computer determines the function setting and only an indication of those not accepted is necessary
preset, homing, exploder, search pattern, stratum, speed, ping interval, doppler enable, depth ceiling, depth floor, search depth change, search pitch,					
synchronous functions, gyro angle, enabling run (run-to-burst), running depth					

TABLE 5-1 (CONT)

Information Requirements	Object Referent	Temporal Aspect	Criticality	Relationship	Display and Control Comments
<u>WEAPON AND TUBE PREPARATION PHASE</u>					
XX Monitor steps in weapon and tube preparation and monitor warnings					
A) Indicators of steps in weapon preparation	own ship	present	b,c	1 and 2 serve as feedback for preparation orders	displayed in relation to preparation ordering controls
B) Indicators of steps in tube preparation	own ship	present	b,c		
C) Warning indicators	own ship	present			
<u>limits</u>			a,b	a and b are meaningful in conjunction with a particular weapon	indicates warning only, not mission failure. suggests alternative action; should be prominately displayed
anti-circular run stratum limits distance limits					
<u>malfunctions</u>			a,b,c		indicates a probable mission failure. must be attention-attracting signals
course voltage low run voltage low wire-guide continuity					
XXI Check acceptance of firing order					
Indication of acceptance	own ship	present	a,b	meaningful with a particular weapon only	displays should be associated with particular weapons and tubes

TABLE 5-1 (CONT)

Information Requirements	Object Referent	Temporal Aspect	Criticality	Relationship	Display and Control Comment
WEAPON AND TUBE PREPARATION PHASE					
XXII Order weapon to be fired in a specific mode					
Firing modes	own ship	present	a,b	same as XXI	same as XXI
impulse silent					
XXIII Order wire-guided torpedo to be guided in a specific mode					
Guidance modes	same as XX				
preset bearing rider corrected intercept					
WEAPON FIRING PHASE					
XXIV Decide when to fire					
A) Kill probability for weapon in question	enemy	present	a,b,c	same as XXI	display for a specific weapon
B) Future kill probability	enemy	projected	a,b,c		kill probability predictor display
increase decrease future time					

TABLE 5-1 (CONT)

Information Requirements	Object Referent	Temporal Aspect	Criticality	Relationship	Display and Control Comments
WEAPON FIRING PHASE					
XXV Decide what actions can be taken to improve kill probability					
Kill probability factors factors which are amenable to manipulation	enemy	projected	a,b	same as XXI	(1), (2) may be provided by books
A) Refine solution of target localization					
sample rate (1) tracking time(2) run another type solution utilize more accurate estimates of target parameters					
B) Own ship maneuvers	own ship	projected	a,b	meaningful only with XXV, A	trial and error display of change in kill probability as a result of contemplated action
decrease range					
XXVI Order weapon to be fired					
A Weapon to be fired	own ship	present	a	same as XXI	same as II
B) Firing time		present	a		time display
XXVII Check firing response					
A) Response indication	own ship	present	a,c	same as XXI	response indicator to be displayed with a particular weapon and tube

total computer failure the manual plot and the torpedo control unit must be substituted.

5.4.2 Weapon Direction

Assuming computer calculation of weapon direction factors, the direct control and guidance of the weapon is a computer function. Essentially, the loop existing between the computer and the weapon is a closed one, except for operator selection of firing and wire-guidance modes.

The initiation of the steps in the weapon and tube preparation sequence resides with the fire control coordinator. The insertion of weapon ballistics into weapon equations is automatic upon loading the weapon into a tube. The corrections for proofing and firing latitudes are up-dated continuously by the computer.

Both the preset and synchronous functions are calculated by the computer on the basis of target position and entered automatically into the weapon. It is apparent, as the number of preset functions increase with each new torpedo type, that the number of setting combinations increase beyond a human's capacity to choose among them. Thus, to effect an attack utilizing the best combinational choice demands some high speed solving device to choose correctly among the alternatives. Allocating the determination of weapon functions to the computer does not imply that the fire control party does not exercise the capability of effecting weapon settings (preset or synchronous).

Instead of attempting to cover fire control errors at both the target localization and weapon direction portions of the problem, the fire control personnel can bring about the best selection of settings by providing the best possible solution for target position. Given an accurate picture of the target's position, including reliable error terms, the computer can determine the best weapon settings to ensure the highest probability of target kill.

Since the active control of weapon functions is not considered a fire control console assignment, the monitoring of the acceptance of the computed functions into the weapon has been assigned to the monitoring station in the control room.

Firing a torpedo at a target is equivalent to firing over a surface of probable target positions. Since the nature of this probability surface can be computed for each target (Ref. 4), based on the target localization data, it is reasoned that to effectively exploit this known function the weapons must be directed and fired in compliance with this function, if the maximum possibilities of killing the target are to be realized. Thus, it is assumed that the spread separation, firing times, and firing order for a salvo of torpedoes will be determined by the computer. This does not imply, however, that the computer will fire at its pleasure. For a single weapon or a spread, an operator will instruct the computer (based on the C.O.'s decision to fire) to commence firing, but the time sequence between each weapon will be controlled by the computer.

5.4.3 Post-firing Guidance

As in the case of weapon preset and synchronous functions the computer will direct the wire-guided torpedo after launching. The necessary input for this control, an error signal indicating the deviation between weapon course and correct course to target, is available in present fire control systems where operators manually control the wire-guides after firing.

There are a number of considerations which might mitigate the argument for such an automatic control loop. First, the bearing data available, which the human controller averages to guide the weapon rather than attending to a particular perturbation, is highly unstable. However, with the envisioned sampling rates of proposed surveillance systems (1 bearing per 2 sec.) it becomes questionable how well the human will serve as an averaging device, yet in any case a computer can be programmed to provide averaged data by rigorous statistical means.

Secondly, the human can intentionally cause a weapon zig immediately prior to hitting the target to bring about a favorable impact angle. It seems, in that case, where the target's course is known precisely enough to enable such control, that the computer could easily be programmed to achieve this same favorable angle.

Finally, for those weapons where the distance before enabling may be changed after launching, the enabling point can be set by the computer as a constant distance from the target. That is, if updating of the target shows that the target has zigged since the initial setting of enabling run, the computer can reprogram the weapon to have an enabling distance commensurate with the target's new position. The same reasoning also applies to the run-to-burst parameter.

In summary, it appears that the task of controlling and guiding weapons can be assumed more and more by the computer and that the fire control party's effort should shift toward providing the best possible information on the target which the computer can use in its equations to accurately direct the weapons.

5.5 OPERATIONAL DESCRIPTION

5.5.1 General

The fire control console has been designed to incorporate the following major features:

1) simultaneous handling of four targets and four weapons.

2) direct utilization of human-determined target parameter estimates in the computer localization solution.

3) detection of target zigs by means of visual displays.

4) evaluation of localization solutions by means of calculated kill probabilities.

5) automatic determination and insertion of weapon control functions by the computer.

6) a means of solving the "ambiguous" consort triangulation problem.

The fire control console (Fig. 5-1) is intended for use by three operators and a fire control coordinator. The task of the center operator

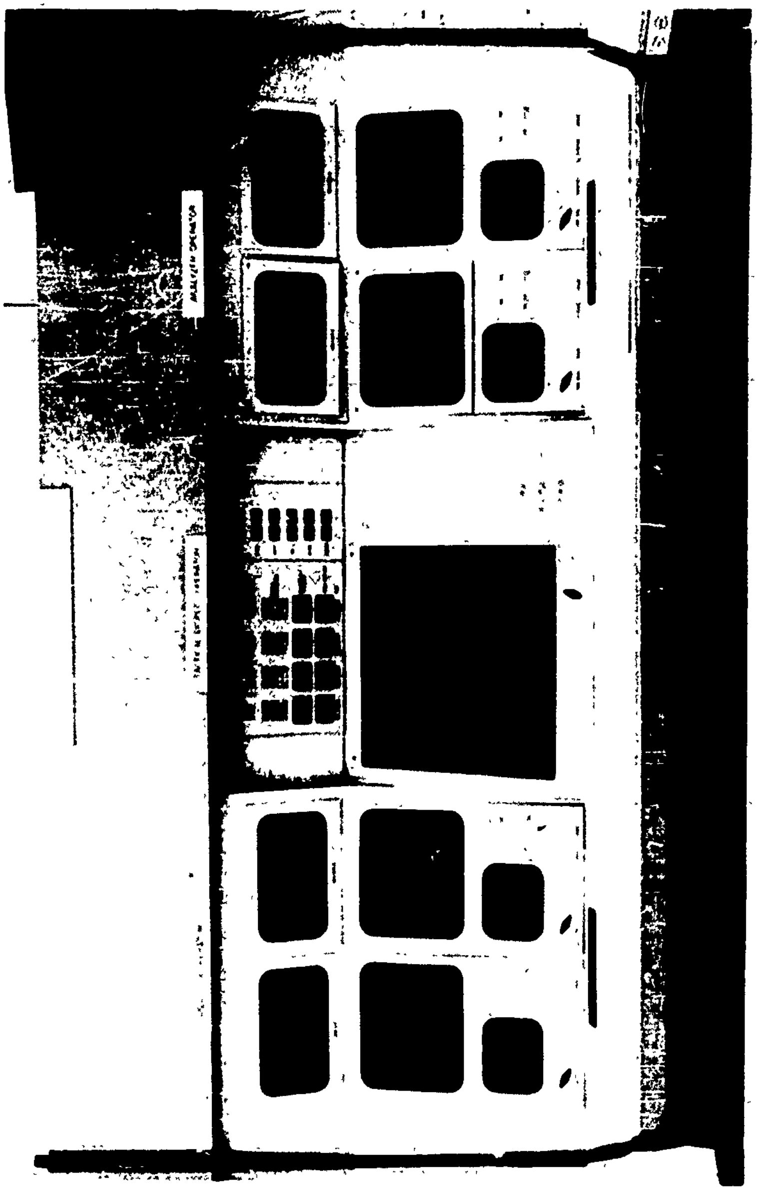

FIGURE 5-1 FIRE CONTROL CONSOLE

is the operation and monitoring of a tactical display and the tube and weapon status panel. On each side of the center position are two target analyzer sections, each containing the necessary displays and controls for analysis of a single target. A single person operates and controls two analyzer sections.

Under battle conditions all three operators will be required for operation, but during normal cruising conditions, when no more than two targets are being tracked, the console can be operated as a tracking facility by one or two operators.

Physically, the console is 7 ft 6 inches wide and 5 ft 1-1/2 inches high. The lower panel reserved for keyboard functions is 10 ft deep and slopes 15° from the horizontal. Above this panel is a 22-inch surface sloped backward 10° from the vertical. The top panel is 12 inches high and is sloped 20° toward the operators. The tactical display panel, centered on the console, is at an angle of 60° and is 28 inches wide. Above the tactical display is a 12-inch vertical panel.

5.5.2 Target Analyzer

The capability of tracking four targets simultaneously requires separate areas to provide for information relevant to each. On the proposed console two target analyzer panels are placed on each side of the tactical display. This arrangement allows interchange of visual and verbal information between the operators of the target analyzers and the tactical display operator. Also the fire control coordinator can supervise all aspects of the console easily.

Each operator has a single keyboard to insert information into either of two analyzer panels and the tactical display. The main features of the analyzer panels are the Target Data, Target Localization (the major interface between the operator and the computer), and the zig detection displays.

Alpha-numeric displays have been used for the Target Data and Target Localization displays in order to incorporate a flexibility into the presentation of target information which is hard to realize with permanent counters and readouts.

For any target it is possible to have a variety of input data which may be used in achieving a localization solution sufficiently adequate for weapon firing. This data may be either sensed via own ship sensors or estimated by human operators. However, seldom is the same type of data available for different targets. Of that data which is available for target localization not all should necessarily be entered into the computer for processing. Thus it seems reasonable to present to the fire control party all information concerning target behavior (Target Data display) and allow these persons to evaluate and select from this same information that which appears appropriate for use in computer processing.

By similar reasoning, selected localization inputs should not be processed by all available processing modes simultaneously. That is, there exists a number of solution methods (computer routines) by which the target can be localized. Seldom are all these routines appropriate to the same target and all use the input data in different ways to provide varying kinds of output information on target parameters. By means of the analyzer keyboards the operators may select both the localization routine and the input data which seem appropriate for that target. In addition, by using the same target inputs in different routines and by using more than one localization routine the operator can evaluate the various localization solutions to obtain the best one.

5.5.3 Target Data Display (Fig. 5-1)
This display presents all sensed and estimated data available for the contact shown in the upper left of the tube face.

On the left side of the display information obtained from own ship sensors is presented showing source, error terms, and the time of sensing.

The right side of the screen contains human estimates of target parameters (including error terms) inserted from the several sonar stations. The catagories of estimates are:

S max, R max, C max, D max - maximum speed, range, course, depth
S min, R min, C min, D min - minimum speed, range, course, depth
S est, R est, C est, D est - actual speed, range, course, depth

5.5.4 Target Localization Display (Fig. 5-2)
Directly below the data display is the localization display which shows the computed solution of range, course, and speed based on the selected localization routine and inputs of target data.

The solution routines available are:

Relative Motion (RM): complete solution based on target bearings plus one target parameter during a single leg of own ship track. A separate solution may be obtained for each leg of own ship track.

Quick Ranging (QR): a single range obtained at time of own ship zig based on bearing rate differences on the two legs.

Mode 2: a bearings-only solution

Mode 24: a bearings-only solution using one or more target parameters.

Maneuvering Target (MT): solution for each separate leg of track for a zigging target from which a mean advance course and range can be obtained.

Progressing to the right across the display, the first column shows the routine selected and the accumulated time that routine has been in progress. For the relative motion cases, this column also shows that part of the output of this routine resulting from bearing processing only: bearing (B); bearing rate ($\dot{B}$); bearing acceleration ($\ddot{B}$); relative angle-on-the-bow (α); least speed (SL). In the second column

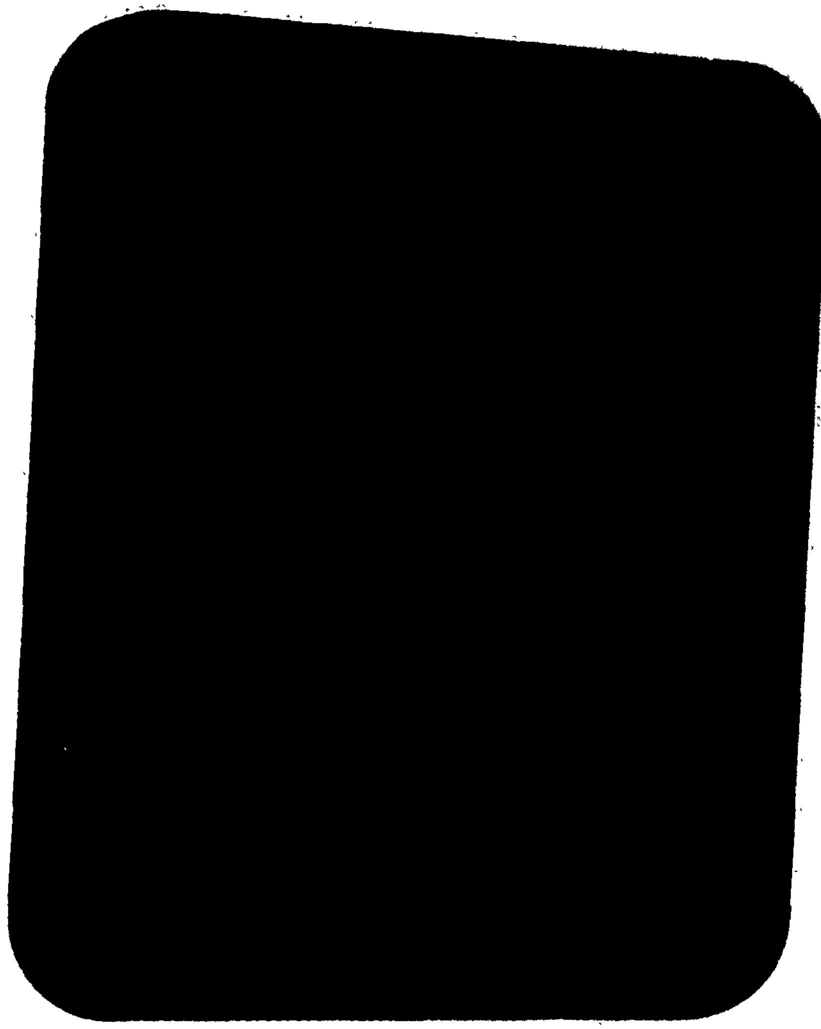

FIGURE 5-2 TARGET LOCALIZATION DISPLAY

appears the input data (coded) from the data display to be used in the routine in question. The third, fourth, and fifth columns are the computed target parameters and their associated errors based on the selected routine and input data.

At the bottom of this screen, under "Weapon Calculation," appears the routine on which kill probability (KP) and weapon direction parameters are computed.

5.5.5 Analyzer Keyboard (Fig. 5-3)
Each keyboard is comprised of a series of labeled buttons for programming the computer and a single line, alpha-numeric unit for displaying the ordered instructions prior to entry into the computer.

The "Analyzer" column contains the buttons for choosing the correct analyzer to receive the instructions. One of the analyzer buttons must be depressed for each set of instructions. In the "Address" column selection is made as to the processing of the target data inputs. Information may be addressed to three processing units of the computer-display complex: computer routine, the tactical display, and weapon calculations for determining kill probability and/or weapon directions.

By means of the "Input Type" and "Input" sections of the keyboard the operator can select the desired target input data to be used in the computer routine. The target data available appears in the Target Data Display at the top of the analyzer panel.

To display kill probability on the Target Localization Display the operator must select both the appropriate weapon and the computer routine on which the calculation is to be based.

The "Tube" column is for assigning the analyzer's target to a tube for weapon direction and firing purposes. The assignment of the weapon to the tube -and thus the target- occurs in the "weapon select" section of the keyboard beside the tactical display.

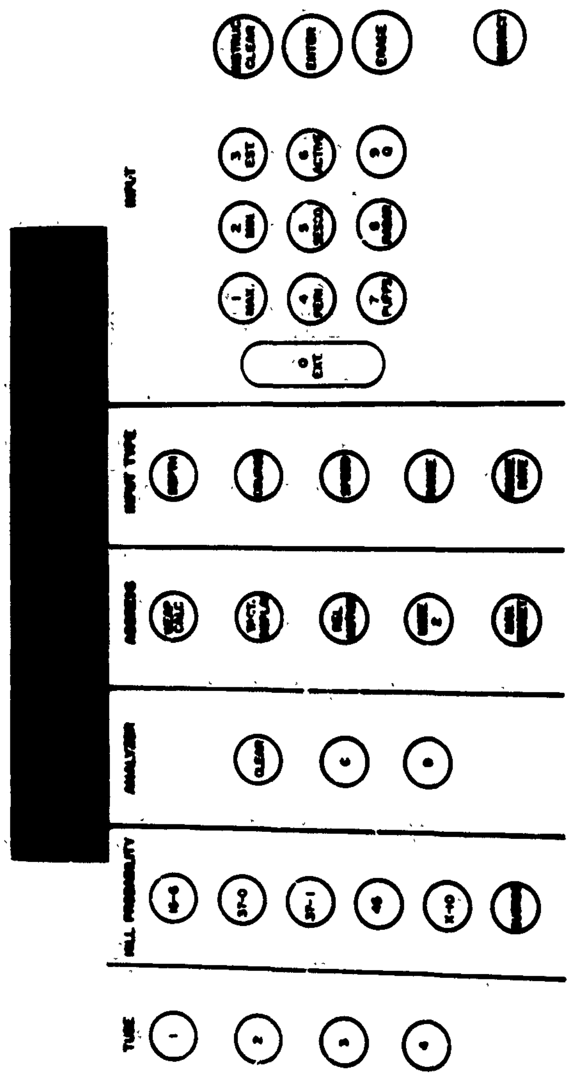

FIGURE 5-3 TARGET ANALYZER KEYBOARD

5.5.6 Zig Detection (Fig. 5-4)
The principal display for detection of a target zig is a CRT which presents the probability that a zig has occurred as a function of time. This measure is based on the history of target bearings and lags slightly behind (1-3 minutes) the actual target zig.

The target analyzer operator detects a zig by deciding when the zig curve differs significantly from the initial baseline. As an aid to zig detection, a criterion line for a zig is presented on the display. This line is based on a mathematical treatment that a zig will have occurred when the curve reaches this criterion line.

5.5.6.1 Sensitivity Control
This control knob allows the setting of the baseline for the zig curve as determined on a straight-running consort vessel.

5.5.6.2 Time Scale Control
This five-position selector switch is used to select a particular time scale over which the zig curve is displayed. The time scales available are: 1, 5, 15, 30, and 60 minutes.

5.5.6.3 Criterion Control and Zig Indicator
This knob allows adjustment of the criterion level. When the zig curve reaches this preset criterion, a zig indicator to the right of the main zig display flashes to indicate a zig has occurred in reference to the criterion.

5.5.6.4 Cursor Control and Zig Entry Button
This control moves a vertical cursor along the time abscissa of the zig detector display. Its function is to inform the computer at what time the operator considers a zig occurred. By depressing the zig entry button, after setting the cursor, the computer is commanded to compute the time since last zig and the mean zig time for all previous zigs of this target. These times are displayed in the readouts designated "Time Since Last Zig" and "Mean Zig Time," respectively.

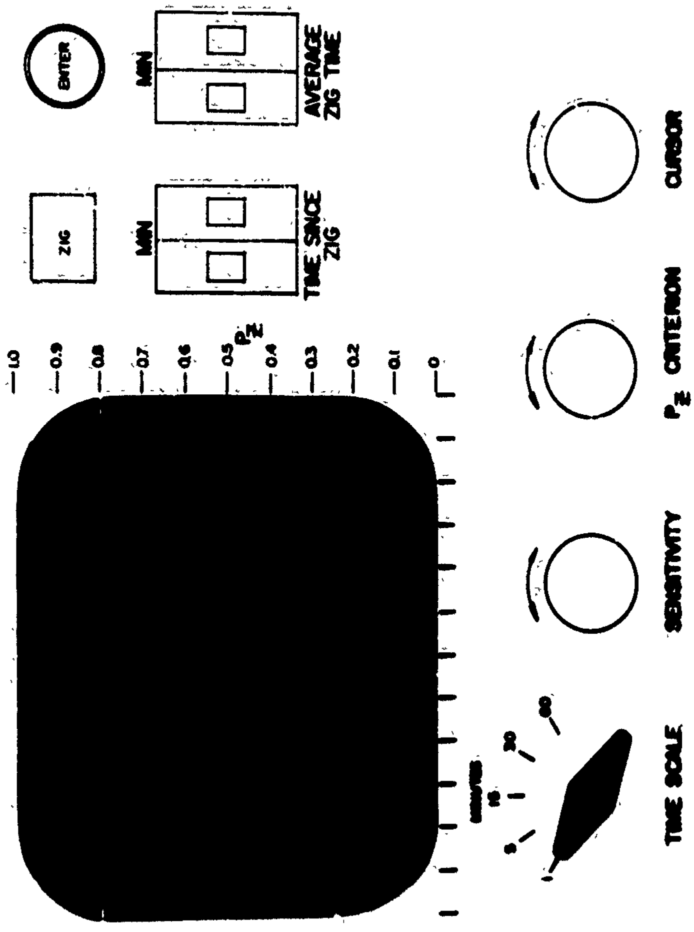

FIGURE 5-4 ZIG DETECTION SECTION

5.5.7 Tactical Display

The tactical display (Fig. 5-1), located at the center of the console, is a summary representation of the current solution status of all targets and consorts taken together. It essentially portrays the individual quantified target data in analog form. Its intended uses are:

1) a means of conceptualizing the total tactical situation.

2) a means of conceptualizing the discrete data on any target to form a decision for the next step in the localization solution.

3) to resolve ambiguities arising in the consort triangulation solution.

4) to supply a "mean advance course" for the zigging target.

5.5.7.1 The Display

The display is generated on a 20-inch square screen.

Own ship is represented by the symbol ⊕ with a tail whose direction and length represent course and speed. Own ship's symbol both rotates and translates. Quantitative readouts of own ship's speed, course, and depth are located to the right of the screen.

Targets are designated by the symbol □ and their appropriate numeric designators. The ways of representing the target's location are dependent on the amount and type of information available.

If only bearing information is available, the location of the target is represented by a single bearing line from own ship.

If, in addition to bearing information, a maximum and/or minimum range become available, a shaded area on the bearing line will be cut off to reflect these limits.

When bearings and an absolute range are obtained, the target is represented by the symbol ⊡ at the correct point with the uncertainty in range displayed as a shaded area around the symbol.

If a complete solution is made, the target is represented by the symbol and a tail to indicate course and speed.

If a maximum speed, maximum range, and maximum course are known for the target a shaded triangle will be displayed.

The consort is represented by the symbol Ô and its bearings to targets by dashed lines. The reason for displaying the consort's target bearings is to solve ambiguities which arise on own ship's targets bearing lines. If the consort's bearing crosses two of own ship's target bearings, the display will aid in determining change of position instructions to the consort to eliminate the ambiguity.

Three controls are provided for the display itself: intensity, range scale, and own ship location. Intensity simply controls the brightness of the symbols on the screen. The range scale selector switch provides the capability of selecting 1, 2, 4, 10, 20, or 40 miles for the display range. The display positioning control is a small joystick, free to move in any direction. Moving this stick upward moves the own ship symbol north, etc., and at the same time preserves the spatial relationships of the display by moving all symbols a corresponding amount.

5.5.8 Keyboard

The information presented on the tactical display may be controlled by the keyboard beneath the display, as well as by the analyzer keyboards. The controls consist of four buttons labeled A, B, C, and D for presentation of bearing and range data of the four analyzers, individually. A fifth button, labeled "All Contacts," displays, in addition to the analyzer contacts, the bearing lines for all other contacts currently being tracked by all ship's sensors. This latter capability is incorporated for determining consort's target.

5.5.9 Tube and Weapon Status Panel (Fig. 5-1)

This area is located at the top of the console's center section and the associated controls are at the right of the tactical display screen. The main purpose of this section is to present information regarding the state of readiness of weapons and tubes.

The four tube columns (labeled 1 through 4) at the center of the panel present information relevant to the preparation status of the weapons in the tubes. As mentioned previously, the target analyzer operator assigns his target to a tube (or tubes if a spread is to be fired). This target designator is displayed below the tube number. The weapon to be fired at the target may be selected by the tactical display operator, or attack coordinator, by means of the weapon buttons on the panel to the right of the tactical display. The weapon selected is displayed below the target designator on the status panel.

Below the weapon designation readouts are three readouts to indicate guidance and firing modes. The guidance modes (bearing-rides, corrected-intercept, or preset) are selected by the center operator. These modes apply only to wire-guided weapons and the readout will indicate "normal" when other weapon types are used. Firing mode can be either silent or normal, the latter being the impulse mode. The choice is based on tactical considerations.

The weapon preparation steps are displayed in five readouts in each tube column. There is a fixed but variable time sequence of steps to prepare any weapon. The operator orders the steps by pressing a single button once for each step. As each step is ordered a light comes on behind the corresponding readout when that step is completed. The orders resulting from depressing the "required order" button are commands primarily to the torpedo room personnel to take the action indicated. The weapon preparation steps are:

Weapon Ready -	load weapon, connect cables, turn on heater power, etc.
Flooded -	tube is flooded
Door Open -	outside door is open
Armed -	weapon is aimed and gyro uncaged
Ready -	weapon is ready in all respects

At the bottom of each tube column are three readouts to indicate "Firing Response," "Firing Time," and "Weapon Malfunctions and Warnings." In the case of a spread, the firing order is determined and displayed by the computer in the firing response readout. When a weapon is fired the word "Fired" appears in this readout. The firing time readout displays the count-down time until the firing of a particular weapon.

The display near the bottom of the status panel indicates for each tube any weapon warnings or malfunctions which have been detected by the monitoring circuits "Malfunctions" suggest a probable mission failure while "warnings" serve notice that the weapon is reaching a limit and a controlling action may be demanded.

To the right of the tube column is the available weapons display. The right-hand column presents the number and types of weapon on board the vessel and the left-hand column the weapons available for immediate firing as a function of their storage position.

The keyboard associated with the tube and weapon status panel is located to the right of the tactical display. Four buttons across the top of the keyboard are numbered to correspond with the four torpedo tubes. Each time an order is inserted a tube number must be pressed to route the order to the proper location.

To assign a weapon to a tube, the operator presses the appropriate tube button and the weapon button.

"Wire Guidance" and "Silent Override" are used to select the wire guidance mode and to select silent launching over the normal launching mode.

The three buttons labeled "Eject", "Abort", and "Fire" are used to select the disposition of the weapon after the preparation sequence has begun. "Eject" forces the weapon into the water. "Abort" stops the preparation sequence by holding all weapon functions at their present state. "Fire" sends weapon on its mission.

The weapon preparation button orders steps in the preparation sequence. It must be pressed once to initiate each step.

VI

COMMAND

6.1 INTRODUCTION

"Command" is that functional unit of the submarine system concerned with the coordination and direction of the system's activities. The most general characterization of the role of the commanding officer is found in Article 0701.1 of the "United States Navy Regulations:"

> "The responsibility of the commanding officer for his command is absolute.....The authority of the commanding officer is commensurate with his responsibility, subject to the limitations prescribed by law and these regulations. While he may...delegate authority to his subordinates for the execution of details, such delegation of authority shall in no way relieve the commanding officer of his continued responsibility for the safety, well-being, and efficiency of his entire command." (pg. 81)

Thus, in the general case, it is clear that the responsibility for all activities within a command rests with the commanding officer; it is likewise acknowledged that the extent and nature of the myriad tasks precludes the commanding officer's performing all of these himself, necessitating the delegation of tasks to subordinates. One problem facing any commander, then, is that of dividing tasks among subordinates and reserving for himself only those tasks which, by virtue of his special qualifications and ultimate responsibility, he can perform best. Such task division is facilitated by the Navy Regulations, which outline some of the commanding officer's specific responsibilities as well as delineating the function(s) of his subordinate officers (for example, the Executive Officer) and the general ship's organization. In short, general guidelines for task delineation and assignment are laid down by the Navy Regulations. Thus, the commanding officer operates within a framework established by the naval organization which, together with traditions and precedents, determine the primary means by which command is exercised.

The fundamental function of the commanding officer is, then, by definition, the organization and coordination of the men and the machines of the sub-systems; the over-riding aspect of this control is to direct these subsystems into accordance with the role defined for them by the naval hierarchy and with national policy. That is, the commanding officer serves as a super-ordinate link designated to control the activities of the system proper, coordinate with the demands of the larger external system (organization) of which the submarine is a unit. The direction thus provided consists of decisions reached from a basic awareness of the submarine's role in a larger context and the integration of the submarine sub-systems to achieve effectively and, if possible, optimally, its designated mission. The means by which this is achieved is defined by the hierarchial organization of the submarine system, in which the commander's function as an integrator of both systems-specific and higher-order considerations has been delineated.

From this point of view, the primary basis for the command function is the flow of information from the naval hierarchy and the submarine sub-systems to the commanding officer. A diagram of the role of command within the submarine system is depicted in Figure 6-1.

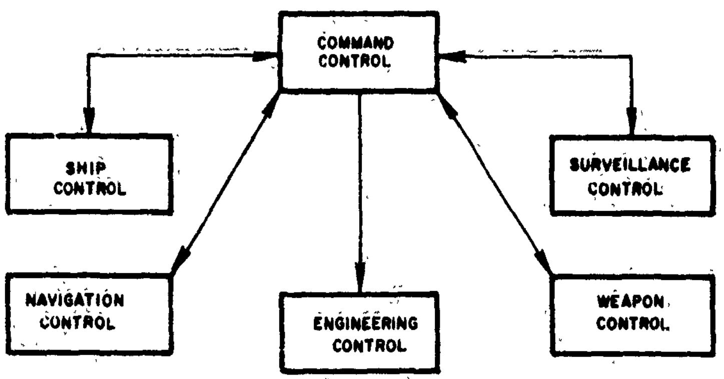

FIG. 6-1 RELATION OF COMMAND TO FUNCTIONAL AREAS OF THE SUBMARINE

This simplified statement defines command in terms of information-transmission in a closed loop system; commands are issued to direct the activities within functional areas or sub-systems which provide feedback regarding the results of those activities. It implies that the commander serves solely as an information processor-decision maker: he initiates action through commands based on informational needs, evaluates (weighs) information derived from that action, and employs it to further direct the activities in any or all sub-systems and, therefore, directs the operation of the ship itself. These tasks are continuous and often simultaneous, in that the commander is often concerned with more than one sub-system at a time. In addition, he must integrate the coordinated ships activities with the over-riding, external demands of national policy, ship's mission, etc.; thus, command decisions operate on two levels, one of coordinating sub-system activities among themselves and the other of integrating system performance with higher-order external demands upon the system.

Figure 6-2 is a more detailed schematic representation of command functioning; while still simplified, it is a better indicator of the problem as it currently exists.

The several external sources of system "forcing functions" are indicated at the left of the schematic; these sources may be thought of as providing information which constrains and directs the commander. It is the commander's primary responsibility to direct the system so as to achieve its goal as defined by and in accordance with the constraints and directives provided. Each source provides an "input" to the commander; such input information is stored (memory, written documents, etc.).

Information from these sources possesses various degrees of relevance or significance, indicated by the variable gain (g) assignment to each. It is presumed that this structuring, either inherent in the information or imposed on it by the commander, will affect its storage and availability from storage; it is also the case that significance varies within information from each source. The net effect of this

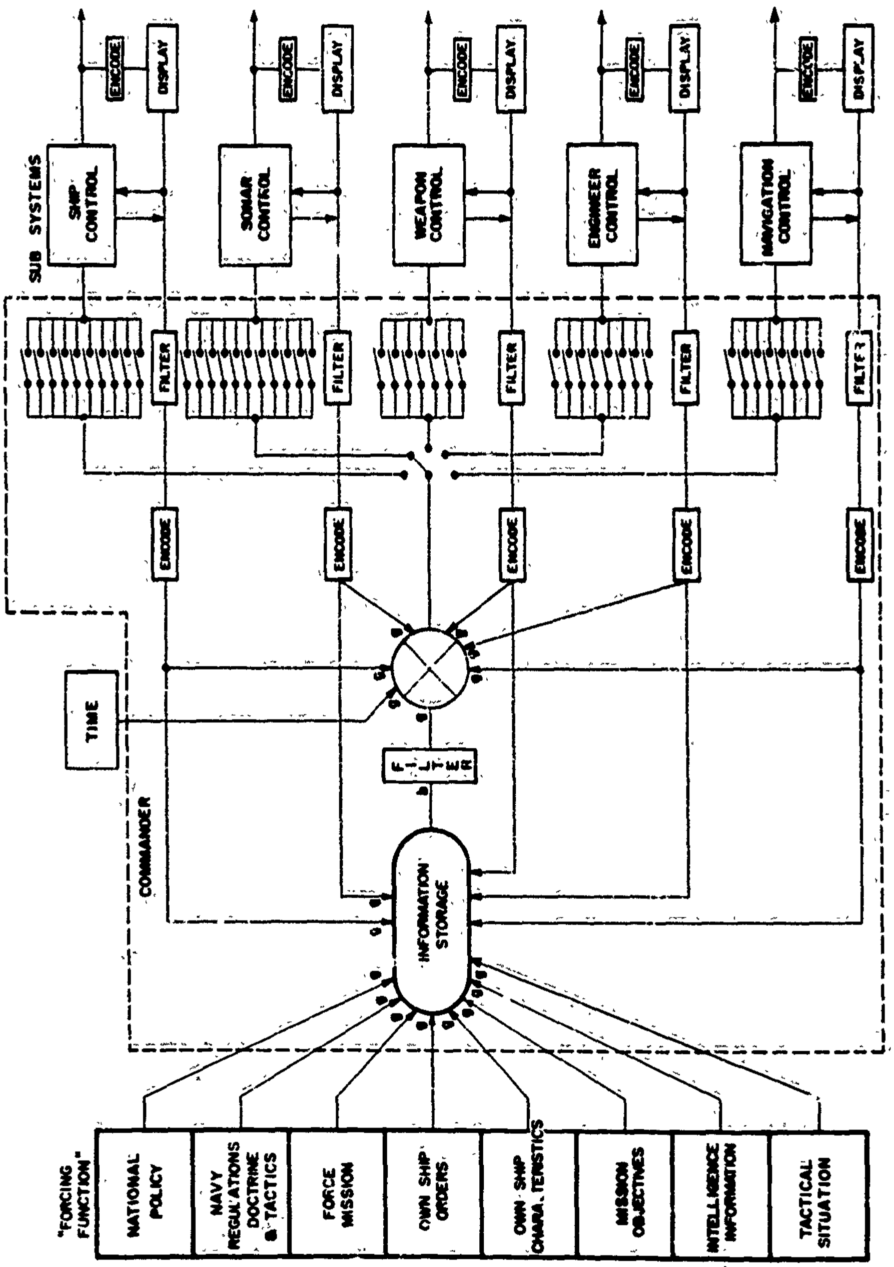

FIGURE 6-2 THE COMMAND FUNCTION

information is to determine command behavior, in the sense that it "forces" him to make decisions (for example, prepare ship for leaving port); such decisions are also partly determined, or affected, by information from the system itself (for example, operating status of the several sub-systems). In terms of the schematic, information flows from storage through a variable filter (this variability is represented by b in the schematic) which "selects" certain information as a basis for action; this information is then "summed" with information from the various sub-systems and a decision made. The nature of the decision determines which of the sub-systems is (are) involved, and which of the command alternatives for each sub-system will be selected for issuance.

The sub-system(s) affected by the command decision and the specific directive(s) issued determine the nature of feedback information. The specific sources of feedback is (are) the display(s) at a given sub-system operating station; the available information may be relayed to the commander by a man at the station or may be read by the commander directly from the display. Both of these means may be adequate when concern is directed toward one sub-system only; in cases where feedback from more than one sub-system occurs simultaneously, the commander is faced with multiple voice communications; the necessity for being in two places at the same time and/or delegation of the decision-making task. In addition, feedback information from each station or sub-system must be filtered, since either more information is likely to be available than the commander can effectively use or some of the information may be irrelevant at the moment. Furthermore, information provided is not necessarily encoded optimally for command; therefore, command encoding may be necessary. These tasks are evident in the schematic, which indicates alternative selection of sub-systems, potential directives for each of these, and feedback from either the display or from the sub-system *per se* (or both). The filter through which this information flows is variable in that the information selected by the commander at any given time from a given sub-system will vary; encoding may or may not be required.

Concern has thus far centered upon those aspects of command function indicated by the schematic; it has already been indicated that the schematic represents a simplification of the functions of command. The basic tasks and problems of evaluating and integrating information to reach appropriate decisions have been suggested: the task is more complex than indicated, since difficulties in interpreting information as encoded by the sub-systems, reception of simultaneous information, the utilization of stored information, the availability of stored information, and the levels of consideration discussed earlier are only generally indicated in the schematic and its accompanying description. Further, those considerations of task delegation necessary to the operation of the system have been largely ignored. Finally, it should also be apparent that the sub-systems included in the schematic are only a sample of those which exist aboard a submarine. Fig. 6-2 serves as a basis for a definition of at least one important command problem and, moreover, points the way toward a solution.

The fundamental assumption inherent in Fig. 6-2 is that the role of a commander is that of processing information and making decisions on the basis of that information. It is in this way that he carries out the function of command, which is the direction of system activity in accordance with the defined mission of the system and within whatever constraints are imposed by higher authority, the environment, and/or unpredicted circumstances. The command tasks implied are:

1) assessing the mission he is assigned and the directives regarding it

2) determining the activities necessary to carry out this mission and the commands they require

3) determining the information required for an effective choice among alternative commands and/or information necessary to issue commands

4) the initiation of activities to provide necessary information and/or achieve some objective

5) the assessment of information provided

6) the choice and issuance of a given command

7) the evaluation of actions resulting from commands

These tasks may be summarized as:

1) determining information needs and initiating activity to provide that information

2) evaluating information gathered

3) selecting a response alternative

4) evaluating results of responses (feedback)

It is assumed that the primary tasks are as pertinent to the ordering of ship's stores as they are to the direction of a torpedo attack. Thus, the commanding officer's basic functions are relatively constant throughout all stages of the ship's mission, although the specific decisions to be made will change as a function of the changing situation.

6.2 THE PRESENT APPROACH

Inspection of Fig. 6-2 reveals specific tasks imposed on the commander which undoubtedly engender inefficiencies in performance: these tasks may be generally characterized as information-processing tasks and they are, specifically:

1) Selecting appropriate information from storage

2) Weighing the significance of that information

3) Integrating it with at least 5 sources of feedback information

4) Sensing feedback information from at least 5 display sources, disparately located, or receiving potentially multiple voice communications, or some combination of these

5) Selecting appropriate information from all the feedback provided

6) Encoding the filtered feedback into a form most readily utilized and most meaningful for his purposes

7) Weighing the appropriate feedback, sending some to storage and utilizing the remainder.

It has already been said of the command function that its goal is the coordinated direction of ship's activity integrated with higher-order directives. Therefore, the central "integrator" is a necessary command function and the sole responsibility of the commander; however, the commander can be relieved of much or all of peripheral encoding, filtering, and integrating. This possibility is illustrated in Fig. 6-3, which shows that the output from the several sub-systems is filtered, encoded, summed, or integrated, and finally displayed to the commander, who need only evaluate the significance or worth of the information displayed and integrate it with information from storage and with ongoing activities.

This solution, that of externalizing some command tasks, is a means of attacking the fundamental issues by stating them in a form amenable to empirical (not <u>necessarily</u> experimental) research and application. The problems are readily apparent in the following set of questions. Beginning at the feedback loop:

1) How can the sub-system output be filtered to provide only that information which is relevant to a command need(s)?

2) How can any information be encoded optimally for command use?

3) How can information be summed or combined for optimal command use?

4) How can information be displayed for optimal command use?

The answer to the first of these rests in large part upon the answers to two further questions:

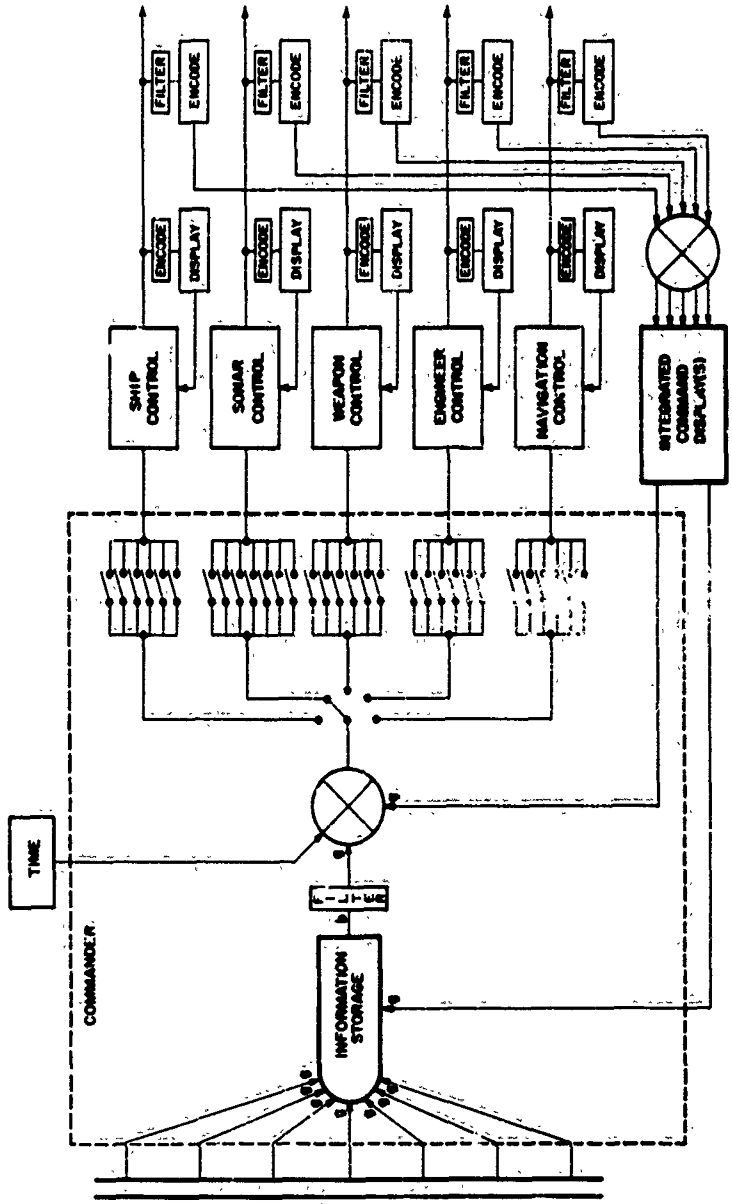

FIGURE 6-3 THE COMMAND FUNCTION SIMPLIFIED

5) What decisions does the commander make?

6) What information does he require to make those decisions?

If command decisions can be delineated, along with the information required to make them, then the problem of appropriate filtering can be approached as can the problem of task delegation.

The problems of appropriate and optimal coding, summing, and displaying information have two components: one of these is similar to filtering, in that the optimal code, summation or summarization, and display(s) is dependent upon the use to which information is to be put, while the second component is relevant to human capabilities and signal characteristics, including such parameters as sensory channel capacity and capability and coding variables such as legibility and intelligibility.

In addition to these long range implications, much is offered toward immediate application which will serve to make more efficient the carrying out of the command function.

The recommendation for enhancing command effectiveness is to externalize as much as possible the information processing aspects of the command function; that is, command should be provided with processed and integrated information, encoded for command use on a display or displays which serve only command. (This reasoning represents the basis for the recommendation of a centrally located command station which has been suggested in past SUBIC reports.) Command is thus relieved of what was termed earlier "peripheral" information processing chores, primarily the tasks of translating and transforming raw data into a usable, "processed" form. The "central" integration of current system performance data and stored data on ships capabilities, intelligence information, and mission objectives remains exclusively the function of command. In effect, this recommendation would relieve command of any "sensor" activities, by which is meant any task which is primarily one of gathering or interpreting raw data. This implies, for example, that the commander would no longer make use of a periscope, but would have

transmitted to him any relevant information obtained from its use, just as he does not serve at the sonar console, but receives from it whatever information is relevant to his needs.

It is necessary, at this point, to qualify the preceding statements. In the absence of a thoroughly exhaustive analysis of command information needs under a plethora of potential environmental contingencies, it is premature to suggest that the commander will never serve as a sensor. It is not unrealistic to assume that at some time under some conditions, when information he requires can be obtained in no other way (that is, not available at the command station), he may need or want to utilize the periscope or monitor the sonar station. Such a possibility is reflected in the general SUBIC control room arrangement, which makes the primary ship's operating stations readily accessible to command. Thus, the commander is not delimited or restricted by the command station, but rather is provided there with the informational basis for primary decisions with the freedom, under circumstances which he can define for himself, to get information from a specific operating station. An effective command station would reduce the variety and frequency of occurrence of such circumstances. Furthermore, the problem of information integration is not simply one of integration versus no integration, but involves rather the definition of integration "levels" or degrees. The reductio ad absurdum of the presentation of integrated information is a single display which reads "yes" or "no" to direct a commander to push or not push a button, the pressing of which causes the system to perform whatever task or maneuver is necessary at any given moment; the extreme of the other end of the continum would require the commanding officer to derive information directly by functioning as ship controller, surveillance operator, fire control resolver, etc. (an equally absurd situation). The optimal point between these is difficult to locate. Regardless of the level of information integration, however, the commanding officer must combine information for his use in directing and coordinating the system. The goal herein is the presentation and processing of information to provide the commander with information form and content for

his purpose and the ultimate enhancement of command effectiveness. In so doing it is necessary to remember that not only are men the most adaptable portion of the man-machine system, but also, and perhaps most significantly, the commanding officer is uniquely trained to perform the task of system guidance. Improved functioning is dependent upon greater understanding and specification of the unique qualifications for decision-making and the determination of the necessary and sufficient information requirements and the detailed delineation of an effective combination of information for decision-making; the emphasis on greater information processing before presentation to command reflects this need and is in response to it.

The command station containing integrated, summary information requires for maximal command utility that the data it displays be filtered, summed, and encoded at some point in the system prior to its appearance at the console. These functions may be carried out either by computers or by sub-system operators; both are currently employed to carry out these functions and both require rules for separating relevant from irrelevant information. Rules for information transmission and encoding are likely to be more dependent on equipment available (for example, the man might transmit by pushing an automatic display button or by verbalization), but rules for ascertaining relevant information are dependent upon command-defined information needs. For a human operator, these may be standard operating procedures, such as advising the commander of any sonar contacts, or may be unique to a situation wherein specific information is provided upon request, such as answering a question regarding the screw count of a target; for a computer, analogous "rules" are programs for automatic display of information and information display only upon command request. In either the human or computer case, the latter categories are determined by momentary needs and require only that the information be available if needed and a means for transmitting it be stipulated; the former case also requires information availability and a transmission means, in addition to the definition of circumstances under which information is to be transmitted.

Ideally, the entire submarine system would be so designed that any information needed by command for any decision would automatically be provided, in an optimally usable form, at precisely the appropriate moment of need. Such an ideal is inherently not realizable, since it would require complete and accurate prediction of all potential contingencies. To the extent that this system is approached, however, command efficiency is enhanced. The basis of the approach is the stipulation of command decisions and their requirements; if these are known in advance, then availability of information, means of transmission, means of display, and automatic or "on-call" presentation may be determined.

6.3 COMMAND DECISIONS AND INFORMATION REQUIREMENTS

Two things are apparent from the foregoing discussion: (1) a command station providing the commanding officer with processed and integrated information will serve to facilitate the command function; and (2) a command station cannot display all possible information to satisfy all possible information needs; therefore, its location should insure easy access to information available at other operating stations. It should display only that information either not available elsewhere or of great consequence to command. The implications of these important points will be more manifest in the section of this chapter concerned with the recommended command station console, its location in the control room and its panel faces, but their relevance here is that they specify the primary problems in the development of the command station and associated displays: what information should be displayed and in what form should it be displayed (that is, how much integration and summary of data is required?).

The answer to the first of these questions would appear to be that information should be displayed which is relevant to command needs and concerns. Since command, as already indicated, concerns the entire system, it is necessary to develop a criterion for information selection, if excessive redundancy is to be avoided. One important criterion is the relevance of information for specifiable command decisions.

In other words, it is reasonable to consider the system and ask what output (decisions) command must provide for system operation to achieve its objectives. Thus, if decisions can be specified as required of command, then the informational bases of these decisions should also be specifiable

One approach to this problem is to ask experienced command personnel to specify the decisions they make and the information which they utilize in arriving at these decisions. Collating such data from a number of commanding officers and integrating it should provide a reasonable approximation of command decisions and information requirements. This approach has been employed in previous SUBIC reports (Ref. 3 and 4), in which experienced command personnel were interviewed extensively and responded to objective questionnaires. The result was a specification of command decisions and information requirements for a submarine system circa 1965-1970. Table 6-1 reflects much of this effort, modified in terms of the recommendations of this report which are more system-specific. The decisions and information requirements which appear in the table to follow are sufficiently detailed and specific to give meaning to the command station and serve as a point of departure for future, more exhaustive analyses as the submarine sub-systems develop and change with technological advances.

Table 6-1 also indicates command objectives and the display implications of command informational needs. The former serve as a context which shape and give meaning to the decisions to be made, while the latter are addressed to the question raised earlier, viz., how shall information needed by command be processed, integrated, and displayed? The table entries under "INFORMATION PROVIDED BY" indicate the display recommendations for the command station console and panel faces. The considerations which led to specific displays for command informational needs will be discussed in the context of the recommended station.

TABLE 6-1

COMMAND REQUIREMENTS

PRIMARY OBJECTIVE(S)	COMMAND DECISIONS	INFORMATION NEEDS	INFORMATION PROVIDED BY:
Ship Control			
Arrive on station	Determine:	Own Ship:	
Minimize detectable outputs	Speed	Present speed	Verbal report, memory, or visual monitoring of ship control
	Depth		
Maximize range/search area through time	Course (heading)	Present depth	Verbal report, monitoring of ship control SQUIRE
Maximize depth/search area through time	Change rates for each		
Avoid obstacles	When to change each	Present heading	Verbal report, SQUIRE, tactical display, memory
Seek out potential targets close to weapon range		Location & fix accuracy	Verbal report, monitoring operations
Optimize: Position for maintaining contact FCS Maneuvering position Position with respect to other targets Disrupt enemy FCS Avoid any enemy weapons		Noise level probability of detecting enemy probability of enemy detecting own ship	Acoustic Detection Environment Display (data expressed in a probability contour which is a function of depth and sound propagation characteristics)
		Environment:	
		Sound propagation characteristics of water temperature gradients salinity gradients ambient noise levels surface and bottom reflection characteristics	Acoustic detection environment display (data integrated and displayed as above)

TABLE 6-1 (CONT)

COMMAND REQUIREMENTS

PRIMARY OBJECTIVE(S)	COMMAND DECISIONS	INFORMATION NEEDS	INFORMATION PROVIDED BY:
		Water depth	Verbal report from sonar
		Bottom contour	Charts, sonar
		Geographic obstacles	Tactical display, verbal reports from sonar
		Sea state, weather, changes in each	
		Enemy: (See Fire Control/Surveillance; decisions that may affect ship control)	
		Enemy Weapon:	
		Range, range at which detected Bearing, bearing drift Bearing to contact Number, type fired Speed, heading, depth	Tactical display and verbal reports from sonar (weapons appear as targets)
Fire Control/Sonar Surveillance	Choice of sonar range sensor or range determination method for FCS		
	Active Sonar: Single or omni-ping	Accuracy of current FCS (if any)	Verbal estimate from fire control, reflected in kill probability
	Transmission power, bandwidth, and rate	Threat to own ship safety Probability of target's detecting ping and taking aggressive or avoidant action	Inferred from tactical display

TABLE 6-1 (CONT)

COMMAND REQUIREMENTS

PRIMARY OBJECTIVE(S)	COMMAND DECISIONS	INFORMATION NEEDS	INFORMATION PROVIDED BY:
		Bearings and bearing drift of target from own ship	Tactical display
		Range estimate of target from own ship	
		Necessity for own ship course change	Recommendation from fire control
	PUFFS	Threat to own ship from target or other targets	Tactical display
		Probability of giving own ship away (due to cavitation, etc.)	Inferred from own ship characteristics, tactical situation, sound propagation characteristics of water (acoustic detection environment display)
	Consort Data:	Existence of Consort	
	SESCO communication initiation	Range and bearing of consort from own ship	Tactical display and/or mission statement
Develop an accurate FCS, maximize kill probability	Own Ship Zig	Bearing of target from own ship bearing drift	Tactical display
	When to zig		
	Direction of zig	Direction of zig (doctrine, tactical situation)	Tactical display, doctrine established
	Rate of change from present heading	Threat to own ship from course change location of other targets maneuvering room	Tactical display and inferences from the data there
	Speed		

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TABLE 6-1 (CONT)

COMMAND REQUIREMENTS

PRIMARY OBJEC[illegible](S)	COMMAND D[illegible]ISIONS	INFORMATION NEEDS	INFORMATION PROVIDED BY:
		possibility of losing target possibility of giving own ship's presence	
		Best time to make zig, duration of zig	Recommendation from fire control
	Sonar [illegible]timate	Estimate accuracy	Tactical display and/or verbal report
	Choice of a[illegible]erna- tives re[illegible] (target range, weapon range)		
	Discontinue track, continue to track	[illegible]rget: Classification [illegible]dition (e.g., s[illegible]rkeling) Bear[illegible]g, bearing drift Course Range Noise le[illegible], echo ranging [illegible]vity	Tactical display, verbal report from sonar
		Possibility of [illegible]en- tually closing [illegible]rget	Prediction of target be- havior, facilitated by tactical display
Dev[illegible] an accurate FCS, [illegible]ximize kill proba[illegible]ty	Continue to track, close to weapon range	Target: Classificat[illegible] Condition (e.g., snorkeling) Bearing, bearing drift Course Range Future position (base course or zig pattern) Probability of detect- ing own ship Noise level, echo ranging activity	Tactical display, verbal reports from [illegible]nar

CO[illegible]FIDENTIAL

TABLE 6-1 (CONT)

COMMAND REQUIREMENTS

PRIMARY OBJECTIVE(S)	[illegible]MAND DECISIONS	INFORMATION NEEDS	INFORMATION PROVIDED BY:
		Own ship: Course, speed, depth Probability of setting within weapon range Time to get within weapon range Threat of exposure through acceleration Threat from other targets	SQUIRE, memo [illegible] prediction from tactical display, course determination by operations. Estimate based or tactical display, acoustic detection display, and own ship characteristics
	Choice of alternatives re target (target range< weapon range)		
	Discontinue track	Target: [illegible]ation Condition [illegible] snorkeling Bearing, bear[illegible] drift Course Range Noise level, echo ranging activity	Tactical display, verbal reports from sonar
	Continue to track to improve FCS	Accuracy of current FCS	[illegible]erbal report from fire co[illegible]trol, reflected in ki[illegible] probability
		Probability of improving it through use of active sonar	Infe[illegible] based on target para[illegible]ters encoded on tactic[illegible]isplay
Develop an accurate FCS, maximize kill probability		Current kill probability	Kill probabi[illegible]y display

TABLE 6-1 (CONT)

COMMAND REQUIREMENTS

PRIMARY OBJECTIVE(S)	COMMAND DECISIONS	INFORMATION NEEDS	INFORMATION PROVIDED BY:
		Threat from delay and/or active pinging Own ship detectability by target(s) Possibility of losing target or degrading FCS	Inferences from acoustic detection display and tactical display
	Continue to track, prepare weapons for firing	Target: Classification Condition (e.g. snorkeling) Bearing, bearing drift Range	Tactical display, verbal report from sonar
		Probability of target zig Average zig time Time since last zig	Tactical display, Alphanumeric display
		Weapon types loaded in tubes	Weapon display
		Kill probability for weapon, weapon guidance and weapon ejection characteristics	Kill probability display
		Probability of target's detecting own ship	Acoustic detection
Develop an accurate FCS, maximize kill probability	Continue to track, fire weapons	Timing of warhead activation and door opening	Essentially based on past experience and is routine, following decision to attack
		Kill probability Probability of hitting own ship with own weapons	Kill probability display Based on depth setting of weapons and own ship depth

Finally, the table does not include any information which is stored information, that is, information available at the start of the mission (for example, ship's orders). Such information is assumed to be available and readily accessible to the commander.

6.4 THE COMMAND STATION

The command station is located centrally in the control room, as described in Chapter 2. The placement of the station in the center of the control room serves to make all other stations and the information they provide readily accessible to the commander through auditory and visual channels. Further, mobility from the command station to any or all of the stations is unhampered. These considerations shaped the command console placement, since much of the information available at the separate stations is required by command and its availability from individual stations facilitates command functioning.

The station itself is designed for either standing or sitting; a removable, adjustable stool is provided for optional use. Although designed for the commanding officer, it is assumed that in his absence the officer of the deck (O.O.D.) will be stationed here. The station is pictured in Fig. 6-4; the height from the deck to the flat top surface from which the control and display panels project is 37 inches, its depth is 34 inches and its length 40 inches. The lower control panel measures 12 inches by 40 inches and projects from the flat top surface at a 15 degree angle; the upper, display panel projects at a 30 degree angle and measures 16 inches x 40 inches. The displays and controls are readily accessible to the man at the station and the console does not hinder his inspection of any of the other control room stations, in accordance with the general notion that these information sources should be readily available to the commanding officer.

The information displayed, the displays themselves, and the controls located on the panel faces of the console derive from the considerations emphasized in this chapter. First, unique information relevant to command, as determined by an analysis of command decisions and shown in

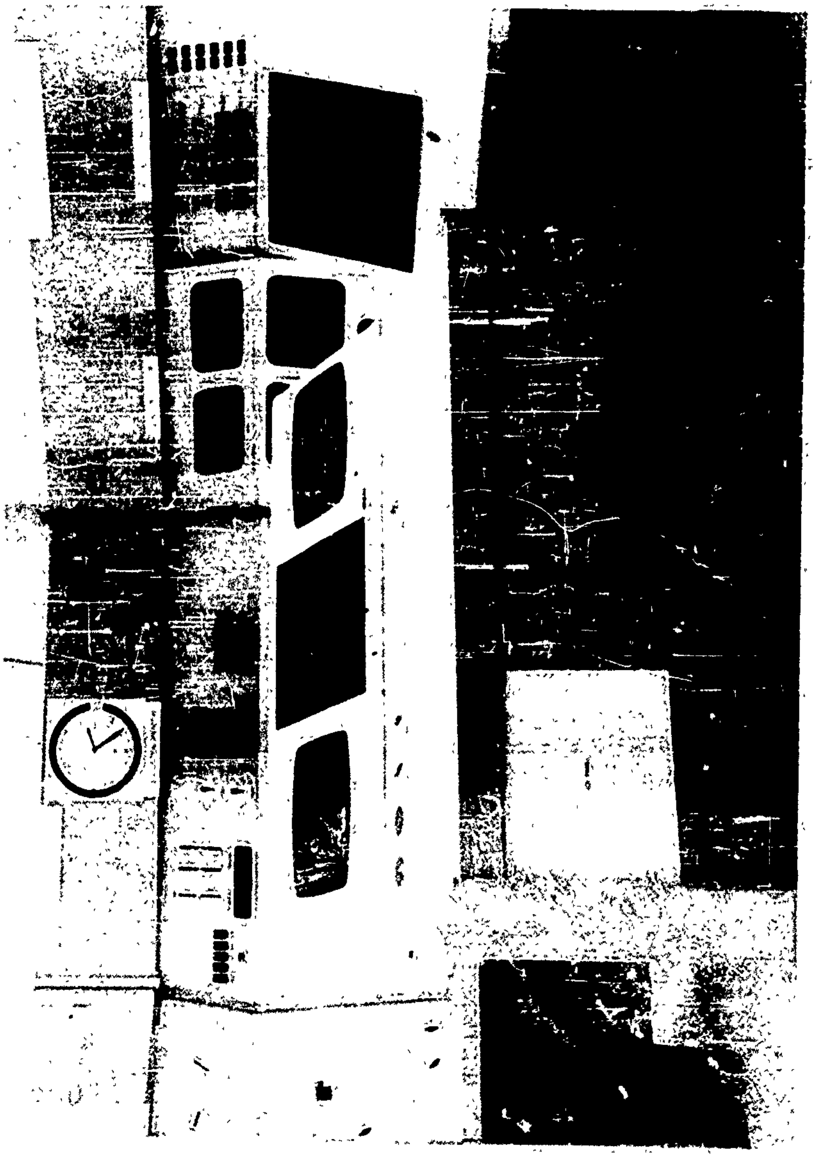

FIGURE 6-4. COMMAND STATION

Table 6-1, represents the content of the displays. The forms or modes of display were conditioned largely by the need to integrate and process data so as to present in coherent and summary form information needed by command. It is apparent, however, from decision requirements that certain information (for example, bearing rate) is needed as a discrete piece of information. The displays, therefore, represent both summary data and discrete information as determined by information needs and by the capabilities of computer processing technology (indicated in another section of this report). When specific information needed by command was available by visual access at another station, it was not repeated at the command station. For example, the ship control SQUIRE display summarizes clearly the position of own ship relative to ordered position; since this display is readily monitored from the command station, it is not duplicated there. Other data, such as kill probability zig time, are available at fire control, but not readily seen by command and, therefore, are duplicated at the command station.

The description of the displays and controls, their operation, and the information displayed reflects (either implicitly or explicitly) the considerations delineated and utilized in their development and described in the preceding pages. The adequacy with which controls and displays meet the stipulated informational needs of command is apparent in Table 6-1 (Table 6-1 indicates how the information is integrated and summarized in displays such as the ACOUSTIC DETECTION ENVIRONMENT DISPLAY (ADED)) and in the description of the displays which follows the table.

6.5 CONTROLS AND DISPLAYS

The control and display panel faces are shown in [illegible]. 6-5. The upper panel is reserved primarily for displays and their controls. From left to right on this panel are: (1) a 7x10-inch CRT, the Acoustic Detection Environment Display (ADED) with associated range and depth controls and a CRT intensity adjustment control; (2) a 12x12-inch CRT, the Tactical Display; (3) a 7x10-inch CRT Alpha-numeric Display of weapon and kill probability data.

FIGURE 6-5 CONTROL AND DISPLAY PANEL FACES

The lower panel face contains controls for the display; controls for the ADED include selector knobs for figure of merit, operation, mode, and probability levels of detection. Controls for the tactical display include a joy-stick for changing the viewed area on the display, a pushbutton for the display of geographic contours and one for weapon range rings; a "past time" selector knob permits the display of past tracks for contacts and/or own ship, as designated by the electronic pencil.

6.5.1 The Acoustic Detection Environment Display (ADED) (Top left of Fig. 6-5)

The ADED is provided to facilitate the commanding officer's selection of an operating depth which maximizes the range at which own ship can detect a target and minimizes the range at which the target can detect own ship. The display consists of a 7"x10" CRT which has an abscissa representing range and an ordinate representing depth. A contour line is projected for any of four probability levels of detection (.25, .5, .7, or .9) which represents either the target's or own ship's detection capability, depending upon the inputs to the display.

The basic input, inserted automatically, is information concerning the sound propagation characteristics of the environment; such information is derived from bathythermograph data, salinity gradients, bottom reflection characteristics, etc. Either target or own ship characteristics, inserted manually from the command station, constitute the remaining inputs; these are either own ship or target sonar figure of merit and depth, inserted via the controls provided below the ADED. Two additional controls are provided for the selection of a functional mode (one mode for target detection, the other for own ship) and a detection probability level to be depicted by the contour. The specific use and interpretation of the display in each mode will be treated separately.

6.5.1.1 Mode 1.

The emphasis in Mode 1 is upon selecting a depth which will maximize the range for the detection of a target. In addition to the sound propagation characteristics of the environment, which are stored in the computer, this mode requires the manual insertion of own ship depth and sonar figure of merit; placing the mode selector at the "contact detection" position which places an own ship symbol on the depth ordinate of the display at the depth selected. The computer determines the range of detection at a given probability level for all possible target depths and the resultant contour appears on the display. From the display the commander can read the ranges for the detection of a target at a specific own ship depth. To determine the effects of changing own ship depth, increasing/decreasing speed or assuming a greater or lesser noise source (speed or noise source changes change the figure of merit), the desired changes are made via the controls and a new contour appears for evaluation. Thus, by manipulating the controls the commander may select a depth and/or speed which results in maximal detection capability for own ship.

6.5.1.2 Mode 2.

The emphasis in Mode 2 is upon selecting a depth which will minimize the target's capability for detecting own ship. Sound propagation data are the same as for Mode 1, while target sonar figure of merit and depth are inserted rather than own ship data. Placing the mode selector at the "own ship detection" position places a target symbol on the depth ordinate of the display at the depth selected. The computer now determines the detection contour of the selected probability level for all possible own ship depths. The depth at which the detection range is greatest as indicated by the contour is therefore the optimal one for own ship to be at; however, since this depth may also limit the capability to detect a target, Mode 1 should be employed in conjunction with Mode 2 to attempt to achieve the optimal relationship between own-ship detection of target and target's detection of own ship.

6.5.2 Tactical Display (Center Display of Fig. 6-5)
The Tactical Display is an 18 inch CRT capable of presenting own ship location relative to targets (contacts) and geographic obstacles. It is similar in appearance and function to the conventional PPI presentation, with the exception that own ship symbol is not necessarily at the center of the display. Information presented automatically on this display consists of:

1) Target bearing (bearing line)
2) Target bearing drift (numerical designation on bearing line)
3) Target speed (numerical designation)
4) Target range and range-error estimates from own ship
5) Target zig (rapid flashing of target symbol)
6) Own ship location
7) Range markings in units of 100 and 1000 yards
8) Target designation from fire control

Information which can be displayed, as a function of the manual controls located below the Tactical Display includes:

1) Weapon range rings with own ship at center
2) Geographic contours
3) Past track for target and/or own ship

Weapon range rings and geographic contours are controlled by the pushbuttons on the control panel and located beneath the Tactical Display, in line with a joystick for recentering own ship (changing viewed area on display); and a scale adjustment knob for the Tactical Display.

6.5.3 Weapons Available, Kill Probability (Right Display of Fig. 6-5)
The final display on the upper panel is an Alpha-numeric display showing weapons in tubes which indicates which weapon types are loaded in which tubes and kill probability data for any weapon, as well as the kill probabilities associated with firing more than one (up to four)

of any weapon. These data appear as available from the computer and can refer to anyone of four targets; contact number and classification appear at the top of the display. The kill probability data serve as an aid in selecting the appropriate weapon, while the "weapons in tubes" indicators serve to remind the commanding officer what weapons he has had loaded; this item, although small, might be critical, since it could indicate changing the weapons in tubes based on kill probability data.

VII

OPERATIONS AND MONITORING STATIONS

7.1 BACKGROUND

During the operational sequence study it became apparent that the four consoles (ship control, command, sonar-surveillance and fire control) could not account for all of the functions performed in controlling the tactical deployment of the submarine. Such functions as navigation, ECM, and radar, and internal communications traditionally associated with tactical submarine deployment were excluded from these areas. While the major effort of the study had to be devoted to the four consoles discussed in the preceding sections, it was nevertheless, deemed essential to include two additional stations (consoles) to incorporate facilities for control of these secondary, but important, functions also.

Accordingly, an Operations and a Monitoring console were added to the control room configuration to permit complete tactical control to be centralized in the control room. The functions associated with these two consoles have been specified at a general level, however, time limitations precluded specifying panel-face details to the same extent as was done for the other consoles in the control room.

7.2 OPERATIONS CONSOLE

As indicated in the frontispiece and Figure 2-1, this console would be located to the left of the ship control console. Its purpose is to provide facilities for the display and control of the following functions or systems:

1) Navigation controls and displays for:
   a) SINS
   b) Loran
   c) Radar (navigation or target localization)

d) Own ship track

e) Star data

f) Maps, charts, and plotting facilities

2) ECM controls and displays for:

a) Signal detection and strength determination

b) Frequency and spectrum analysis

c) Classification

d) Pulsed signal analysis

e) Receiving equipment control and selection

3) Internal voice communications control

4) Intercept course display system

5) TV periscope

The first three items listed include those systems now in being or which can be modified for the 1965 time scale. The latter two items constitute new developments and are new or expanded capabilities.

7.2.1 Intercept Course Predictor System

This is a new display system whose purpose is to perform a maneuvering board solution for intercepting a target. The data furnished is used by command in selecting a course to close a given target. Input controls are manipulated in accordance with the commander's needs; the operator in this case acts as an effector link for the commander to the computer. The system is shown in Fig. 7-1; it consists of a Geographical Display (useful also in the navigation function) and a series of controls which enable setting in variables in an equation. The commanding officer decides what bearing relative to the target and what range from the target he wants to close the target. Appropriate controls are set by the operator. Average target course is calculated when the switch for that purpose is pressed. Having fixed these parameters of the equation, two additional variables are entered by means of suitable controls, i.e., course, speed, or time. The

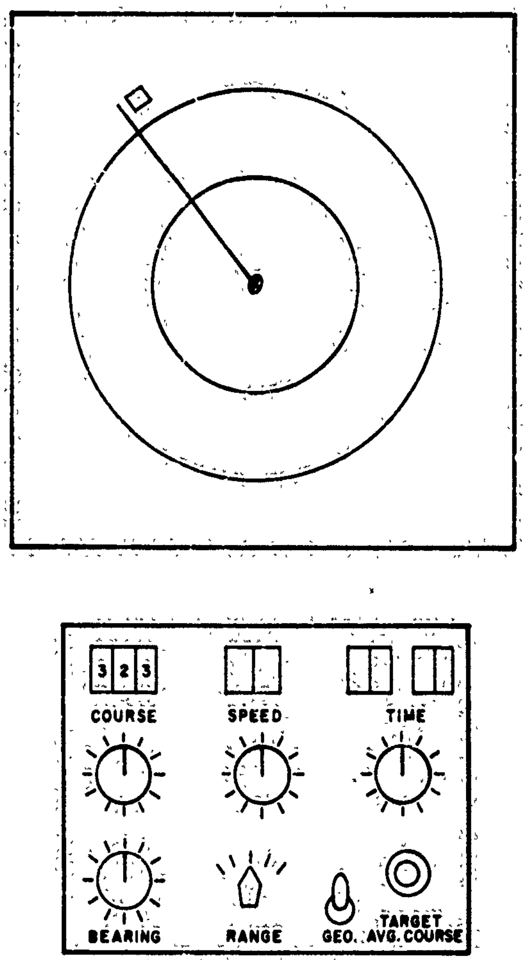

FIGURE 7-1 INTERCEPT COURSE PREDICTOR SYSTEM

computer then calculates the third variable. Digital readouts above the course, speed, and time control furnish the desired data. For example, if an intercept course is desired, speed and time are inserted via appropriate controls and course is read out on the digital indicator. Thus, the commanding officer can obtain direct predictive information regarding specific courses or speeds to select for an intercept course or to determine the amount of time required to intercept a target. Alternative solutions can be obtained by varying the parameters of the equations as desired.

7.2.2 TV Periscope

The Operations Console includes provision for display of the TV periscope and remote monitoring of an optical periscope, if this latter is required. Since, in most cases, the TV periscope will provide better and more accurate viewing at far lower light levels than the optical periscope, it is expected that this addition will supplant the optical periscope for most uses. An optical periscope could serve both as a backup for the TV periscope and also be available for navigational starsights. The optical periscope will be located outside the control room, however, monitoring of its view can be provided on the Operations Console for the benefit of control room personnel as needed.

7.2.3 Advantages Afforded by the Operations Console

The advantages associated with the inclusion of an Operations Console are:

1) provision of a central location for control of those functions essential to tactical submarine deployment not controlled from other consoles in the control room;

2) that command may exercise direct supervision of the functions located on this console, and he can profit by the displays incorporated on it;

3) inclusion of the intercept course predictor system which provides most of the advantages associated with a maneuvering board, but should be much easier to use;

4) introduction of the TV periscope with its capabilities for improved viewing; and,

5) a further extension of the integration philosophy of centralizing all control functions affecting ship tactical deployment into a single integrated system.

7.3 MONITORING CONSOLE

A Monitoring Console is located in the control room as shown in the frontispiece and Figure 2-1. Since this console reflects a new concept, made possible to some extent by the capabilities of the digital data processor, it is desirable to consider the assumptions and rationale upon which it is based.

Assumptions and Rationale for a Monitoring Console

1) A central monitoring capability can increase the submarine's combat effectiveness by providing a facility for systems monitoring unique in the following ways.

a) The capabilities of the central data processor may be utilized for maintenance by at least three methods;

1) for logical circuit analysis to isolate failures,

2) by means of digital comparison techniques to isolate changes from optimal performance levels in systems and subsystems, and

3) by the use of statistical methods to isolate probable sources of failures.

b) Provide (by the techniques listed above) fault isolation to system or subsystems.

c) Determine performance degradation from optimum levels.

d) Provide a central location for monitoring routine functions.

e) Provide an area for redundant monitoring of highly critical functions.

The bases for this assumption are demonstrated capability of fault location using digital techniques and the capabilities of large scale digital machines for logical analysis and their ability to utilize statistical and comparative techniques.

2) Centralizing certain monitoring functions can reduce the work load at other stations. This will permit more effective operation at these stations while, at the same time, providing more effective monitoring of the functions centralized.

The basis of this assumption is that an area devoted primarily to monitoring can perform this sin[illegible] function better than a station concerned with both operati[illegible] [illegible]trol and extensive monitoring. This is particularly t[illegible] [illegible]ctions monitored are incidental to the contr[illegible] [illegible] not all functions monitored can or even shoul[illegible] [illegible]zed, those functions which can be appropriately c[illegible] [illegible] [illegible]rease the monitoring task requirements a[illegible] [illegible]ach individual console thus ensuring better performance of the primary functions of the several stations.

3) A centralized monitoring capability will increase equipment operating time by reduction of down time.

The basis of this assumption is the fact that sizeable proportion (as much as 70%) of down time is devoted to locating the source of failure. With adequate equipment performance monitoring and at least some degree of automatic trouble isolation, this cause of down time can be significantly reduced.

4) A central monitoring capability can provide more effective maintenance control (both preventive and corrective) by better utilization of maintenance personnel.

The basis for this assumption is that automatic trouble isolation and performance monitoring combined with proper maintenance personnel control will provide optimal use of both men and machines and thus increase maintenance effectiveness. This will serve to extend equipment operational time and, when failure does occur, reduce the amount of time needed to restore normal operation.

5) A central monitoring capability will improve the decision-making effectiveness of command by providing more precise knowledge of equipment performance status.

The basis for this assumption is that more precise knowledge will allow more realistically based tactical and operational decisions to be made.

There are several distinct advantages attendant with adoption of the monitoring console concept. These have been indicated in the assumptions upon which the concept is based. It should be emphasized that maintenance and performance monitoring will add to the capabilities of the submarine by direct attack on the major cause of equipment down time = trouble isolation. Since up to 70% of down time is used in isolating failure, a system which will reduce troubleshooting time must decrease the time that equipment is out-of-commission. Equipment operational time will thereby be increased.

As the complexity of equipment increases and the number of electronic circuits in new equipment becomes greater, the capability of automatic trouble isolation to subsystems or components becomes increasingly important. It may well be that the limitations of automatic trouble-shooting will constitute the limits for equipment design. The USS TULLIBEE SS(N)597 in its sonar system alone, for example, has some 50,000 transistors in addition to vacuum tubes and other components. Even if the probability of failure were .01 per 1,000 hrs, statistically, 500 failures per 1,000 hrs could be anticipated in the reliable transistor circuits. Thus, the use of the digital computer to aid in the solution of the maintenance problem is a logical consequence resulting from its potential usefulness in this area.

The Monitoring Console will perform three general functions:

1) Provide a central location capable of performing many of the monitoring functions now located on other consoles. In this connection, certain critical monitoring tasks could be duplicated on the monitoring console to provide redundant monitoring if needed.

2) Provide for performance monitoring of various equipment systems to give early warning of potential system failure.

3) Perform maintenance monitoring using the digital computer's capabilities to provide automatic or semi-automatic trouble isolation when a failure occurs.

Of immediate concern are the latter two functions; performance and maintenance monitoring, since these will add most to present submarine capabilities.

Two preliminary studies (references 1 & 2) have dealt with the problems of performance and maintenance monitoring. The problems to be resolved are the following:

1) What equipment most needs monitoring?

2) What is the required frequency of monitoring?

3) What type of monitoring will be most effective?

4) What type of display will be most beneficial?

5) How can monitoring equipment best be isolated to prevent interaction with the monitored equipment?

The following systems will be considered in detail: They appear in what is believed to be descending order of operational time, that is, equipment used most:

SONAR	ECM	FIRE CONTROL
PERISCOPE	RADIO	LORAN
		RADAR

The heart of the monitoring systems will be in scanning circuitry. The logic involved will be developed as the individual systems are studied in detail. An automatic scanning procedure based upon POMSEE (Preventive Operational Maintenance of Shipboard Electronic Equipment) would be an ideal base from which to expand, for example.

POMSEE provides specific, periodic, manual tests to be performed on the system concerned. A proper POMSEE check gives the operational status of the equipment, but necessarily only periodically as the tests are performed manually. With automatic scanning, a continuous POMSEE-like check can be maintained thus enabling detection of irregularities.

It is also probable that continuous monitoring (continuous might mean seconds to several minutes) could pinpoint the source of the fault when, or even before, it occurs. Thus time-consuming troubleshooting by a technician would be eliminated or minimized. This time saved could be an important item, particularly during combat, as about 70% of electronic repair time is spent in fault-finding and diagnosis (troubleshooting). The logic circuits necessary to provide this capability could be added or programmed into the digital data processor as an expansion of automatic POMSEE.

Measurement of power supply voltage levels and system resistances to ground should detect approximately 75% of the troubles in the previously listed systems. In some systems, final stage current could detect otherwise unnoticeable faults. Parasitic antennae will be essential for performance checking of transmitting equipment.

While the displays have not been completely specified at this time, in general, they would consist of groups of lights, readouts, and meters. They would show the status (operational, marginal, or inoperable) of each monitored system and such things as expected down time and amount of performance degradation, if marginal.

Isolation of monitored systems from the influence of the monitoring system is necessary to prevent a new source of malfunction. Several isolation techniques are available from simple switching to automatic

lock-out features. Safety devices, for example, could consist of relays, magnetic amplifiers, and/or solid state devices.

The whole monitoring system concept is based upon capabilities for growth. The system will obviously have to be expandable to cover new equipment as it is added. With integrated design, the only limiting factor should be size, and size relative to the size of monitored components should be small.

VIII

OPERATIONAL SEQUENCE

8.1 INTRODUCTION

As a test of the feasibility of the panel-face layouts, the Human Factors section was responsible for the development of a sequence of a submarine operational mission which was to include the following situations:

1) getting underway
2) piloting
3) transit
4) surveillance
5) ASW action-snap shot
6) ASW action-General Quarters
7) selected casualties

The rationale underlying the operational sequence is that once developed, it would be applied to each of the consoles to determine if the proposed panel-face layouts could satisfy the requirements indicated in the sequence of operations. If they could, and the operational sequence itself was valid, then the panel-face layouts would have passed a first test in demonstrating their feasibility.

This section describes the development of the operational sequence, including the assumptions upon which it was based and the method employed in developing it. The sequence itself will be found in paragraph 8.5 of this report.

Before proceeding further in this report, the meaning of the term "operational sequence" should be made clear. In a broad sense the term refers to a list of certain activities which occur in a given situation and are arranged in an order of occurrence. As used in this study these activities include verbal commands, responses to commands,

inter-station communications, and operator actions. The sequence of operations includes the activities occurring in the control room and bridges areas. In those situations where an order originates in these areas but is carried out elsewhere, the sequence is restricted to the activities in the control room and bridge.

It must be emphasized that an operational sequence is not an ultimate test of a proposed panel-face layout. It cannot suggest the optimum display or control necessary in a given situation. It cannot even insure that a display or control is valid for a given situation. What it can provide, however, is an indication of the functions which must be fulfilled in a given situation. It is not uncommon, in programs which involve a major reorganization and redistribution of functions, to "lose" one or more functions in the process. Thus, in a new or revised system each new station might assume that the other stations were fulfilling function "X" whereas, in fact, none of them were. An operational sequence, drawn from existing systems and well-constructed, can can isolate such "lost" functions and bring them to the attention of investigators early in the development program.

Other characteristics of value, which an operational sequence can be expected to indicate, include the following:

1) the temporal relationship of the various entries

2) the frequency with which various events may be expected to occur

3) the interaction among the functional areas.

8.2 ASSUMPTIONS

The operational sequence study was, of necessity, based on several assumptions. These assumptions, together with their rationales, are indicated below.

Assumption 1 The Operational Sequence Study assumed that the submarine under consideration would be an attack-type, advanced THRESHER Class design.

The bases for this assumption were the task statements for the Bureau of Ships and Bureau of Naval Weapons and the numerous SUBIC memoranda, which indicated that the hull of the submarine to be studied during Phase V of the SUBIC program would be of an advanced THRESHER design.

Assumption 2 The Operational Sequence Study assumed that the mission of the submarine under consideration would be to seek out and destroy enemy submarines and surface ships.

This assumption was made on the basis of information contained in the text, "Submarine Fire Control and Tactics Manual," published by the U.S. Naval Submarine School, and on Assumption 1 above, which specifies an attack-type, as opposed to an FBM type submarine (Ref. 7).

Assumption 3 The Operational Sequence Study assumed that the submarine under consideration would be capable of firing any of the following weapons:

Torpedo Mk 16 Mod 6

Torpedo Mk 37 Mod 0

Torpedo Mk 37 Mod 1

Torpedo Mk 45 Mod 0

SUBROC

EX-10

The basis for the above assumption was the capability of the Mk 113 Fire Control System (presently the most advanced, operational equipment), which can launch any of the above. More advanced weapons were not included in the assumed capability because their

development programs are not sufficiently advanced to define the operation of all controls associated with pre-firing and guidance modes of the weapons .

Assumption 4 The Operational Sequence Study assumed that the mission situations specified earlier are discrete and do not occur simultaneously.

This assumption was made purely for expository reasons. It is apparent that the situations are not, necessarily, mutually exclusive. For example, piloting could take place during on-station patrolling, if the patrol area is just off a land mass. In the same vein, an ASW action could occur while in transit. However, to avoid redundancy, and to provide continuity to a hypothetical submarine mission, the situations were assumed to be discrete events.

8.3 METHOD

In deriving the operational sequence the concern was primarily with a delineation of the situations, the selection of sequential entries, and the method of presentation. Each of these areas is discussed briefly in the following sections.

8.3.1 Delineation of the Situations

The first phase of the study was directed toward a delineation of the seven situations. To obtain definitions as realistic as possible within the constraints of the given situations, structured interviews were held with General Dynamics/Electric Boat personnel who were, while on active duty, qualified in submarines. Secondary sources of information were pertinent texts, such as Knight's Modern Seamanship, and The Watch Officer's Guide. From information thus acquired, tentative definitions were derived and utilized in a rough draft of the first three operational sequences.

It was soon apparent, however, that certain limitations were inherent in the situations as given. For example, the separation of the conditions Getting Underway and Piloting appeared artificial in the context

of a sequence of operations. It was also apparent that presentation of selected casualties could best be made by incorporating the casualties into the other situations rather than presenting them as isolated situations, since casualties occur only within the context of some other situation. Accordingly, (a reexamination was made of the seven original situations) with the goal of consolidating or re-structuring them in a more realistic and functional manner. This resulted in the following changes:

1) the Getting Underway and Piloting situations were combined

2) the ASW Snap Shot and Selected Casualties situations were eliminated as separate situations, but were incorporated in those remaining

3) the Surveillance situation was renamed "On-Station Patrol"

As a result of these changes, the situations were reduced in number from seven to four. (It should be noted again, however, that the incidents covered in the eliminated situations are included in the remaining situations.) These were then redefined in light of the above changes. The results, which represent the situations as finally constituted, are given below.

8.3.1.1 Definition of Situations

Situation 1 Getting Underway

This situation pertains to the period during which the submarine gets underway from its berth and stands out of the harbor. The situation begins with the stationing of the Maneuvering Watch, and continues so long as the submarine is maneuvering in the channel or along the coast where aids to navigation are available for fixing position. It ends when landmarks are no longer discernible, or the submarine has submerged.

Situation 2 Transiting

Transiting refers to that period during which the submarine is enroute from its operating base to its operating area. The situation commences when the submarine has cleared the coast and taken departure for its assigned area or has submerged. The period terminates when the submarine is on station.

Situation 3 On-Station Patrol

The patrol situation selected for study in this report is one in which the submarine is on station and conducting a continuous search for sub-surface and surface targets. The situation begins when the submarine arrives on station and terminates when the submarine leaves its operating area.

Situation 4 ASW-GQ Action

An ASW-GQ action refers to the period during which the submarine detects, classifies, approaches, and attacks an enemy vessel under optimum conditions of material and personnel readiness. The situation begins with the detection of a target (in this instance, while patrolling on station); it terminates when the submarine breaks off the attack and no longer is in immediate danger.

8.3.2 Selection of Sequential Entries

Phase 2 of the study was concerned with the selection of the events to be included in the four situations. It was apparent that all events transpiring during an operational mission could not possibly be included in the sequence; therefore, selection of appropriate activities was made on the basis of recommendations obtained from operating personnel. These activities, although not all-inclusive, were felt to be representative of those which one might reasonably expect to encounter aboard an attack-type submarine at sea. They are indicated in the list below.

Getting Underway

1) preparation
2) entering the channel
3) piloting

Transiting

1) submerging
2) operations at periscope depth
3) gyro failure

On-Station Patrol

1) approach on surface ship
2) ECM contact
3) power failure
4) snap-shot action

ASW-GQ Action

1) detection and classification
2) approach
3) attack

After selection of the gross events to be included in the sequence, the process of data collection in the field was begun. To facilitate this process, the situations were divided into two general areas: 1) the more prosaic activities, such as getting underway and piloting; and 2) those activities which involved an approach or attack against an enemy vessel.

Sequential entries for the first category were drawn from three sources:

1) USS THRESHER Organization and Regulations Manual (Ref. 8)
2) Quartermaster log books from USS SKIPJACK
3) Interviews with qualified submarine personnel

The various operational bills contained in the THRESHER organization manual, such as the Maneuvering and Diving Bills, provided valuable data of a general nature. More specific items were obtained from field visits to the forces afloat. An initial interview was conducted with the Operations Officer of Submarine Squadron 10 concerning the goals of the study, the most promising sources of information, and the maneuvering problems peculiar to single-screw ships. Subsequently, interviews were held with commissioned officers aboard USS SKIPJACK, during which unfamiliar entries and terminology contained in their quartermasters' logs were clarified.

Sequential items for the remaining category (approach and attack) were drawn primarily from special log books concerning nuclear submarine

exercises, obtained from the Submarine Development Group Two. Supplementing these items were entries from pertinent printed matter, particularly the tactical doctrine for the Mk 37 Mod 0 torpedo, and training films of the Submarine School dealing with approach and attack tactics (see references). These sources enabled the investigators to complete the rough drafts of the final two situations. The situations were then presented to officer-instructors of the Tactics Division, U.S. Naval Submarine School, for critical review. Following incorporation of their suggestions into the narrative, it was apparent that a marked weakness still existed in the details of the snap-shot incident. Accordingly, a final field visit was made to the office of the off-duty crew of USS PATRICK HENRY, where attention was focused on this area, and the necessary data were obtained.

8.3.3 Method of Presentation

Having selected items for inclusion in the sequence, it remained to develop a format to present them in a useful manner. It was apparent that some form of tabular presentation would be desirable, as this would allow simultaneous presentation of items. The problem of the manner of categorization of the sequential items was met by developing a series of column headings which represented broad functional areas. These areas corresponded roughly to those presumably associated with the four console faces and were titled "Command, Ship Control, Sonar, and Fire Control." (The presumption was necessary because the functions assumed by each console were not known at the time.) A fifth area, Operations, was added to provide some indication of the remaining functions which must, ultimately, be accounted for.

The advantage of using functional areas, rather than console titles, as table headings was that such areas corresponded generally to the consoles and thereby, facilitated the testing process, yet were not restricted to the functions ultimately assigned the consoles. Thus, the investigators had freedom to proceed without waiting for completion of the functional analyses of the consoles by other investigators. It must be emphasized that inclusion of a sequential item in a given functional area does not suggest that it should be necessarily handled by the equivalent console.

8.3.3.1 Definitions of Functional Areas
Brief statements of the scope of the functional areas, as used in the operational sequence, are given below.

Command Area
The Command area refers to that area which assumes ultimate responsibility for the direction and control of the total submarine system so as to achieve the mission objectives.

Ship Control Area
The functions of ship control encompass all those operations that pertain to control of the velocity, spatial attitude, and orientation of the submarine.

Sonar Area
The sonar area includes the functions associated with the detection, classification, and localization of all waterborne noise sources.

Fire Control Area
The function of the fire control area is to launch and control a weapon so that it collides with or explodes near a target and, thereby, causes the target's destruction.

Operations Area
The Operations area includes responsibility for the safe navigation of the ship and for the transmission and reception of all electromagnetic radiation external to the ship, exclusive of sonar.

8.4 INTERPRETATION OF THE SEQUENCE
The operational sequence is presented in paragraph 8.5. A few notes are in order concerning its interpretation.

1) The sequence presents only selected events from a hypothetical operational mission. No attempt was made to include all events possible, or even likely, as such an effort was beyond the scope of the present phase. An attempt was made, however, to select events which were representative of those activities commonly encountered or anticipated in a given setting.

2) With few exceptions, the manner in which given incidents were handled represented only one of several possible ways of coping with these incidents. It was not meant to imply that the manner depicted necessarily was doctrine. The events as described, however, are believed to be entirely feasible within the context of a given situation.

3) The reader should note the "intial conditions" pages which precede each of the four situations covered in the sequence. These, together with the assumptions stated in this chapter, provide the background necessary to interpret the events covered in the situations.

4) With respect to the column labeled "Time" in the sequence, the numbers in this column represent time in minutes since the beginning of the situation.

8.5 OPERATIONAL SEQUENCE DETAIL

8.5.1 Getting Underway

Initial Conditions

A state of war is considered to exist between the United States and a foreign power.

The submarine is moored portside to a finger pier at a U.S. Naval Operating Base, with standard mooring lines doubled.

During the past 48 hours the ship has been making preparations for sea, in accordance with a given operations order. During this interval it has received aboard a full warload of weapons, and supplies and equipment for an extended patrol at sea.

The operations order directs the submarine to proceed to a specific station and conduct offensive operations against enemy sub-surface and surface targets.

The operational sequence is outlined in Table 8-1.

TABLE 8-1
GETTING UNDERWAY

TIME	COMMAND	SHIP CONTROL	SONAR	FIRE CONTROL	OPERATIONS
0	▷ "STATION THE MANEUVERING WATCH"	○ MANS STATIONS	○ MANS STATIONS	○ MANS STATIONS	○ MANS STATIONS
5	○				▷ "REQUEST PERMISSION TO RAISE AND ENERGIZE MASTS"
6	▷ "PERMISSION GRANTED"				○ RAISES MASTS; TESTS RADAR, AND ESTABLISHES RADIO COMMUNICATION WITH BASE
[illegible]		□ TESTS STEERING SYSTEMS AND RUDDER ANGLE INDICATOR	□ TESTS AND CHECKS SONAR SYSTEMS	□ TESTS AND CHECKS FIRE CONTROL SYSTEMS	
		□ TESTS ANNUNCIATORS			○ RECEIVES "MANEUVERING WATCH SET" REPORTS FROM ALL COMPARTMENTS
	○	□ TESTS MAIN INDUCTION VALVES			▷ "MANEUVERING WAT SET IN ALL COMPARTMENTS"
11	▷ INSTRUCTS OPERATIONS TO REQUEST PERMISSION TO GET UNDERWAY				○ TRANSMITS REQUEST TO GET UNDERWAY
					□ TESTS FATHOMETER
12	○	▷ "REQUEST PERMISSION TO TEST SCREW ON TURBINES AND PROPULSION MOTOR"			□ TESTS ALL ALARMS FROM EACH STATION
					□ CHECKS GYRO REPEATERS AGAINST MASTER GYRO

▷ INFORMATION TRANSMITTED
○ INFORMATION ADDRESSEE
○ ACTION ADDRESSEE
□ SELF-INITIATED ACTION

TABLE 6-1 CONT'D
GETTING UNDERWAY

TIME		COMMAND		SHIP CONTROL	SONAR	FIRE CONTROL		OPERATIONS
1[illegible]	△	"PERMISSION GRANTED"	○	TESTS SCREW			□	CHECKS PERISCOPE BEARING TRANSMITTERS AGAINST GYRO
			□	CHECKS AIR OUT IN TO WHISTLE			□	CHECKS MANEUVERING GM CLOCKS AGAINST GM WATCH
							□	TESTS RUNNING LIGHTS AND SEARCHLIGHT
							□	ENERGIZES ALL IC CIRCUITS
							□	CHECKS PERISCOPE OPERATION
							□	TESTS MC SYSTEMS
[illegible]							○	RECEIVES PERMISSION FROM BASE TO GET UNDERWAY
	○						△	"PERMISSION GRANTED TO GET UNDERWAY"
[illegible]	○	RECEIVES READINESS REPORTS FOR GETTING UNDERWAY FROM DEPARTMENT HEADS						
[illegible]							□	DELIVERS SAILING LIST TO APPROPRIATE OFFICE, OR MAILS
	○						△	"READY IN ALL RESPECTS FOR GETTING "UNDERWAY"
20	△	"SINGLE UP"						

TABLE [illegible] (CONT)
GETTING UNDERWAY

TIME	COMMAND	SHIP CONTROL	SONAR	FIRE CONTROL	OPERATIONS
[illegible]	Δ "TAKE IN THE BOW; TAKE IN #2 & 3; [illegible]"				
[illegible]	Δ "TAKE IN [illegible]; CHECK [illegible]"				
	Δ "MANEUVERING, STAND BY TO ANSWER BELLS"	O ORDERS MANEUVERING TO STANDBY			
	[illegible] "RUDDER AMIDSHIPS"	O PUTS RUDDER AMIDSHIPS			
[illegible]	Δ "TAKE IN [illegible]"				
	Δ "ALL BACK [illegible]/3"	O RINGS UP ALL BACK [illegible]/3			
	Δ "RIGHT FULL RUDDER"	O PUTS RUDDER RIGHT FULL			
31	Δ "ALL STOP; SHIFT THE RUDDER"	O RINGS UP ALL STOP; SHIFTS RUDDER TO LEFT FULL			
	Δ "ALL AHEAD 2/3"	O RINGS UP ALL AHEAD 2/3			
[illegible]	Δ "ALL STOP; ALL BACK 2/3"	O RINGS UP ALL STOP AND ALL BACK 2/3			
	Δ "SHIFT THE RUDDER"	O SHIFTS RUDDER TO RIGHT FULL			

TABLE 8-1. CONT'D
GETTING UNDERWAY

TIME		COMMAND		SHIP CONTROL	SONAR	FIRE CONTROL		OPERATIONS
[illegible]	△	"ALL STOP; SHIFT THE RUDDER"	○	RINGS UP ALL STOP; SHIFTS RUDDER TO LEFT FULL				
	△	"ALL AHEAD 2/3"	○	RINGS UP ALL AHEAD 2/3				
[illegible]	△	"MEET HER"	○	CHECKS THE SWING				
	□	MANS PELORIS - OBTAINS BEARINGS						
	△	"STEADY ON COURSE 170°"	○	STEADIES UP ON 170°				
[illegible]	△	"ALL AHEAD 1/3"	○	RINGS UP ALL AHEAD 1/3				
	○						△	"CLEAR CHANNEL"
[illegible]							□	MAINTAINS CONTINUOUS GEOGRAPHIC PLOT OF SHIP'S POSITION; PROJECTS TRACK AHEAD
[illegible]	△	"COMMENCE CONTINUOUS SOUNDING"					○	DETERMINES DEPTH FROM KEEL
							△	"DEPTH TO KEEL - 10 FM." 'REPEAT EVERY MINUTE'
	□	MANS PELORIS - OBTAINS BEARINGS						
42	△	"COME RIGHT TO 174°"	○	CHANGES COURSE TO 174°				

TABLE 6-1 (CONT)
GETTING UNDERWAY

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
	▷	"CONTINUE RIGHT TO 177°"	○	CONTINUES SWING TO 177°						
44	▷	"NOTHING TO THE LEFT OF 177°"	○	ALLOWS NO DEVIATION TO LEFT OF 177°						
46	▷	"ALL AHEAD 2/3"	○	RINGS UP ALL AHEAD 2/3						
	▷	"RANGE TO OUT-BOUND SHIP AHEAD"							○	DETERMINES RANGE TO SHIP AHEAD
	▷	"COME LEFT TO 171°"	○	CHANGES COURSE TO 171°						
	○								▷	"RANGE TO SHIP AHEAD - 1220 YDS"
48	▷	"RANGE TO SHIP AHEAD"							○	DETERMINES RANGE
	○								▷	"RANGE TO SHIP AHEAD - 990 YDS"
50	▷	"INDICATE 67 REVO-LUTIONS"	○	ORDERS 67 RPM						
53	▷	"SECURE REPORTING CONTINUOUS SOUND-INGS, BUT ADVISE OF ANY SOUNDING LESS THAN 5 FATHOMS"							○	
55	▷	"COME LEFT TO 168°"	○	CHANGES COURSE TO 168°						
57	▷	"COMMENCE BEAM TO BEAM SONAR SEARCH"			○	COMMENCES SEARCHING FORWARD OF BEAMS				

CONFIDENTIAL

TABLE [illegible] (CONT)
GETTING UNDERWAY

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
[illegible]	○				▷	"NO CONTACTS OTHER THAN SURFACE SHIP OFF STARBOARD BOW"				
[illegible]	▷	"COMMENCE 3 [illegible] SEARCH"			○	COMMENCES FULL SEARCH				
[illegible]	▷	"SECURE THE MANEUVERING WATCH, SET THE REGULAR SEA DETAIL, SECTION 2 HAS THE WATCH"	○	SETS REGULAR SEA DETAIL	○	SETS REG. SEA DETAIL; CONTINUES FULL, CONTINUOUS SWEEP WITH SONAR	○	SETS REGULAR SEA DETAIL	○	SETS REGULAR SEA DETAIL; MAINTAINS GEOGRAPHIC PLOT; PROJECTS SHIP'S TRACK
	○				▷	"NO ADDITIONAL CONTACTS"				
	▷	"ALL AHEAD STANDARD"	○	RINGS UP ALL AHEAD STANDARD						
[illegible]	▷	"RIG SHIP FOR DIVE"	○		○		○		○	
	○								▷	"RECOMMEND 162°"
[illegible]	▷	"COME LEFT TO 162"	○	CHANGES COURSE TO 162					○	
	○		▷	"REQUEST PERMISSION TO TEST PLANES AND BRIDGE HATCHES"						
	▷	"PERMISSION GRANTED"	○	TESTS PLANES AND HATCHES						
	○		▷	"REQUEST PERMISSION TO TEST BLOWING OF TANKS"						

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TABLE [illegible]-2 (CONT)
GETTING UNDERWAY

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
	▷	"PERMISSION GRANTED"	O	TESTS AIR TO MBTs						
	O								▷	"RECOMMEND COURSE 110°"
[illegible]	▷	"LEFT 15° RUDDER; STEADY ON COURSE 110°"	O	"YES RUDDER LEFT 15°", STEADIES ON COURSE 110°					O	
11	O								▷	"SHIP NOW IN INTERNATIONAL WATERS"
			O	RECEIVES 'RIGGED FOR DIVE' REPORTS FROM ALL COMPARTMENTS						
			□	INSURES THAT SHIP IS PROPERLY COMPENSATED						
[illegible]	O		▷	"SHIP RIGGED FOR DIVE AND COMPENSATED"						
[illegible]	▷	"RANGE & BEARING OF POINT DELTA"							O	DETERMINES RANGE & BEARING OF POINT DELTA
161	O								▷	"POINT DELTA, BEARING 355° TRUE, RANGE 28000 YDS"
162	▷	"ADVISE WHEN DELTA BEARS 325°"							O	
214	O								▷	"RADAR CONTACT, BEARING 117° TRUE, RANGE 12000 YDS"

TABLE 8-1 (CONT)
GETTING UNDERWAY

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
	▷	"KEEP RANGES & BEARINGS COMING"							○	
217	○								▷	"CONTACT NOW BEARS 119° TRUE, RANGE 12400 YDS"
220	○								▷	"CONTACT BEARS 122°, RANGE 13100 YDS"
223	○								▷	"POINT DELTA NOW BEARS 325°, RANGE 31500 YDS"
224	▷	ORDERS BRIDGE PERSONNEL BELOW								
22[illegible]	□	INSURES THAT BRIDGE IS CLEARED AND FULLY SECURED FOR DIVING, DESCENDS TO CONTROL ROOM								
227	J	SOUNDS DIVING ALARM								

8.5.2 Transit

Initial Conditions

At the beginning of the situation the submarine is rigged for dive on the surface, but with all preparations for submerging completed. The COD has secured and cleared the bridge, and has descended into the control room. The ship is on course 110°, engines ahead standard, as the diving alarm is sounded.

Two primary activities are covered in this situation: the dive itself, and the interval during which the submarine planes to periscope depth. A casualty in the form of a gyro failure is also included.

The operational sequence is outlined in Table 8-2.

TABLE 8-2
TRANSIT

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
0	□	SOUNDS DIVING ALARM	□	OPENS ALL MAIN VENTS; SHUTS VENTILATION EXHAUST VALVES; SHUTS OUTBOARD INDUCTION VALVE; PUTS RUDDER AMIDSHIPS; RINGS UP ALL AHEAD 2/3; TESTS PLANES	○		○		□	SECURES LOWER BRIDGE HATCH; SECURES RUNNING LIGHTS, IF ON; TIMES THE DIVE
									□	MANS IC TELEPHONE AND RECEIVES REPORTS FROM ALL COMPARTMENTS
	○		▷	"STRAIGHT BOARD"						
	○		▷	"PLANES WORKING SATISFACTORILY"						
1	▷	"110 FT"	◯	PLANES TOWARD ORDERED DEPTH					○	
			□	SHUTS ALL MAIN VENTS (WHEN PASSING 45 FT)						
	○		▷	"ALL VENTS SHUT"						
	○								▷	"ALL COMPARTMENTS ON THE LINE"
2	□	MONITORS PERTINENT ASPECTS OF SHIP CONTROL	□	PROCEEDS TO ORDERED DEPTH						
	○				▷	"NO CONTACTS"				

▷ INFORMATION TRANSMITTED
○ INFORMATION ADDRESSEE
◯ ACTION ADDRESSEE
□ SELF-INITIATED ACTION

TABLE 8-2 (CONT)
TRANSIT

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
3	▷	"ALL AHEAD 1/3"	O	RINGS UP ALL AHEAD 1/3					O	
[illegible]	▷	"GET A SATISFACTORY TRIM"	O							
	O		▷	"PERMISSION TO CYCLE THE VENTS"						
[illegible]	▷	"PERMISSION GRANTED"	O	CYCLES THE VENTS						
6			□	MANIPULATES TRIM CONTROLS TO OBTAIN SATISFACTORY TRIM						
1[illegible]	O		▷	"STEADY ON 110 FT; TRIM SATISFACTORY"						
			□	SHIFTS TO AUTOMATIC MANEUVERING CONTROL						
13	▷	"SECURE THE PHONES"							O	ORDERS PHONES SECURED
1[illegible]	▷	"ALL AHEAD FULL; 200 FT - 10° DOWN ANGLE"	O	RINGS UP ALL AHEAD FULL; DIVES AT 10° TO ORDERED DEPTH					O	
1[illegible]	O		▷	"STEADY ON 200 FT"						
20	O				▷	"BIOLOGICAL NOISE BEARING 164°"				

TABLE 5-2 (CONT)
TRANSIT

TIME	COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS	
[illegible]	○		▷	"GYRO FAILURE - GYRO FAILURE"						
31	▷	"SHIFT REPEATER INPUT FROM MASTER TO AUXILIARY"							○	
31	▷	"SHIFT TO MANUAL CONTROL; STEER MAGNETIC HEADING"	○	SHIFTS FROM AUTOMATIC TO MANUAL CONTROL - COMMENCES STEERING BY REFERENCE TO MAGNETIC COMPASS						
34	○								▷	"AUXILIARY GYRO NOW ON THE LINE"
35	▷	"SHIFT TO AUTOMATIC CONTROL WHEN SYSTEM HAS STABILIZED"	○	COMPARES MAGNETIC HEADING WITH NEW REPEATER HEADING; WHEN COINCIDENTAL, SHIFTS BACK TO AUTOMATIC CONTROL						
36	○		▷	"REPEATER BACK ON THE LINE; HAVE SHIFTED TO AUTOMATIC CONTROL"						

TABLE 8-2 (CONT)
TRANSIT

TIME	COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS	
1600	▷	"ALL AHEAD 1/3"	O	RINGS UP ALL AHEAD 1/3					O	
1601	▷	"MAKE PREPARATIONS TO DUMP GARBAGE THROUGH THE GDU"							O	RELAYS ORDER
1602	▷	"100 FT"	O	PLANES TO 100 FT					O	
1604	▷	"RIGHT 10° RUDDER; STEADY UP ON 270°"	O	PLACES RUDDER RIGHT 10°; COMES TO COURSE 270°					O	
1605	▷	"SEARCH THE BAFFLE"			O					
	O		▷	"STEADY ON 270°"						
1608	O				▷	"NO CONTACTS"				
1609	▷	"RIGHT 10° RUDDER; STEADY UP ON 090°"	O	PLACES RUDDER RIGHT 10°; COMES TO COURSE 090°					O	
1610	▷	"PREPARE TO VENTILATE"	O	RAISES INDUCTION MAST; CHECKS NEGATIVE FLOOD SHUT; OPENS NEGATIVE VENT; OPENS INDUCTION DRAIN TO NEGATIVE TANK						
1620	▷	"STANDBY FOR RADIO AND ECM RECEPTION"							O	CHECKS RECEIVERS, ANTENNA PATCHING, AND TAPE RECORDERS FOR PROPER OPERATION
1621	▷	"70 FT"	O	PLANES UP TO 70 FT					O	

TABLE 6-2 (CONT)
TRANSIT

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
1622	○		▷	"STEADY ON 70 FT"						
	▷	"LOOK AROUND"	○						○	
[illegible]	□	RAISES PERISCOPE - MAKES 3?O? SEARCH	□	COMPENSATES AS NECESSARY						
[illegible]	▷	"[illegible] FT"	○	PLANES UP TO 6[illegible] FT					○	
[illegible]	□	CONTINUES VISUAL SEARCH WITH PERISCOPE								
[illegible]	▷	"[illegible] FT"	○	PLANES UP TO 62 FT					○	
[illegible]	▷	"RAISE WHIP AND ECM MASTS; SEARCH ALL BANDS"	○	COMPENSATES AS NECESSARY					○	RAISES WHIP ANTENNA AND ECM MAST TO OPERATING POSITIONS
									□	COMMENCES COPYING FLEET BROADCAST; COMMENCES SEARCHING ALL ECM BANDS
[illegible]	○		▷	"RIGGED TO VENTILATE; TRIM SATISFACTORY"					▷	"NO ECM CONTACTS"
1631	▷	"COMMENCE VENTILATING"	○	OPENS INDUCTION AND VENTILATION EXHAUST VALVES; STARTS LOW PRESSURE BLOWERS; STARTS INDUCTION BOOSTER FANS						
1632									□	ADJUSTS RECEIVERS FOR LORAN FIX

TABLE B-2 (CONT)
"TRANSIT"

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
[illegible]	▷	"LOAD THE ODU"							○	RELAYS ORDER TO ENGINEERING
[illegible]	▷	"PUMP BILGES; BLOW DOWN THE BOILERS"	□	COMPENSATES FOR PUMPING, AS NECESSARY					○	RELAYS ORDER TO ENGINEERING
									□	SECURES FROM TAKING LORAN FIX; PLACES RECEIVERS IN STANDBY
[illegible]	○								▷	"NO ECM CONTACTS"
[illegible]	○				▷	"POSSIBLE NOISE LEVEL BEARING 320°"				
	○								▷	"ENGINEERING REPORTS SECURED FROM BLOWING BOILERS"
[illegible]	○				▷	"CONTACT BEARING 320° EVALUATED AS FISH"				
									□	SECURES FROM COPYING FLEET BROADCAST; LOWERS ANTENNA; PLACES EQUIPMENT IN STANDBY
	○								▷	"FLEET BROADCAST SECURED; ANTENNA LOWERED"
1660	○								▷	"SECURED THE ODU"
1666	○								▷	"ENGINEERING REPORTS ALL BILGES DRY; SECURED PUMPING"

TABLE 8-2 (CONT)
TRANSIT

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
1670	○								▷	"ALL SCHEDULED OPERATIONS COMPLETED"
1685	▷	"SECURE VENTILATING"	○	SECURES THE LOW PRESSURE BLOWER; SHUTS THE INDUCTION AND VENTILATION EXHAUST VALVES; SHUTS INDUCTION MAST DRAINS TO NEGATIVE TANK; LOWERS INDUCTION MAST; SECURES THE INDUCTION BOOSTER FANS; SHUTS NEGATIVE VENT						
[illegible]	○		▷	"SECURED FROM VENTILATING"						
[illegible]	□	LOWERS PERISCOPE	□	COMPENSATES AS NECESSARY						
[illegible]	▷	"200 FT"	○	PLANES DOWN TO 200 FT					○	

8.5.3 On-Station Patrol

As the situation begins, the submarine is submerged on station, and patrolling its area in accordance with a prescribed pattern. Initially, its course is 055°, speed five knots, and depth 300 feet. It holds no contacts on its sonar. The submarine has two tubes ready in snapshot condition, and two additional tubes loaded but secured. Unless otherwise specified, all weapons are assumed to be torpedoes Mk 37 Mod 0.

During this situation the submarine makes an approach on a surface ship, is forced deep as a result of an ECM contact, sustains a power failure, and fires two weapons under snapshot conditions.

The operational sequence is outlined in Table 8-3.

TABLE 8-3
ON-STATION PATROL

TIME	COMMAND	SHIP CONTROL	SONAR	FIRE CONTROL	OPERATIONS
0	○		▷ "FAINT NOISE LEVEL, BRG 010°"	○	
1				□ PLACES F/C CONSOLE IN OPERATION; SELECTS APPROPRIATE SENSOR AS INPUT	
[illegible]	○		▷ "NOISE LEVEL BRG 009°, WEAK AND INTERMITTENT"	○	
[illegible]	○		▷ "NOISE LEVEL BRG 005°"	○	
5	▷ "LEFT 15° RUDDER; STEADY ON 000°"	○ PLACES RUDDER LEFT 15°; STEADIES ON 000°			○
[illegible]	○		▷ "NOISE LEVEL BRG 004°; EVALUATE AS MECHANICAL; DESIGNATE AS CONTACT S-4"	○	
7	▷ "STATION THE TRACKING PARTY"		○ TRACKING PARTY MANS STATIONS; ONE SUB-SYSTEM IS DIRECTED CONTINUOUSLY AT S-4; ANOTHER MAKES FULL SWEEPS	○ TRACKING PARTY MANS STATIONS; SELECTS METHOD OF TARGET ANALYSIS; CHECKS LATITUDE PROOFING AND FIRING DISPLAYS; DETERMINES SPEED CORRECTION, IF NECESSARY, AND INSERTS INTO BALLISTIC PLUGS; CHECKS TUBE BALLISTIC SWITCHES; CONTINUOUSLY MONITORS BEARING INPUTS FROM SENSORS; ALSO OWN SHIP INPUTS FOR COURSE, SPEED, DEPTH; COMMENCES TARGET MOTION ANALYSIS	

▷ INFORMATION TRANSMITTED
○ INFORMATION ADDRESSEE
○ ACTION ADDRESSEE
□ SELF-INITIATED ACTION

TABLE 9-3 (CONT)
ON-STATION PATROL

TIME	COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS	
[illegible]	▷	"MAKE TURNS FOR ? KTS	O	ORDERS TURNS FOR 3 KTS					O	
[illegible]	O				▷	"CONTACT BRG 001°, 3 DB LOUDER, SLOW SPEED SCREW, LIGHT CAVITATION; PROBABLE MERCHANTMAN"	O			
	O								▷	"XXX FREIGHTER HAS BEEN REPORTED IN THIS AREA"
	▷	"SONAR, CAN YOU GET A TURN COUNT?"			O					
	O				▷	"NEGATIVE"				
	O				▷	"NOISE LEVEL BRG 095°, EVALUATED AS BIOLOGICAL"	O			
45	O						▷	"REQUEST COURSE 270° TO AID FIRE CONTROL SOLUTION"		
26	▷	"LEFT 15° RUDDER; STEADY ON 270°"	O	PLACES RUDDER LEFT 15°, STEADIES ON COURSE 270					O	
27	O				▷	"S-1 BRG 000°"	O			
[illegible]	O				▷	"S-1 BRG 357°, D/E ANGLE +15°, MODERATE CAVITATION"	O	ENTERS D/E ANGLE; ATTEMPTS ANALYSIS OF TARGET DEPTH		

TABLE 8-3 (CONT)
ON-STATION PATROL

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
[illegible]	O				▷	"S-4 BRG 358°, TURN COUNT 62, SINGLE SCREW: ESTIMATE SPEED 8 KTS: CLASSIFY AS MERCHANTMAN"	O	ENTERS TARGET SPEED ESTIMATE INTO MOTION ANALYSIS		
	O						▷	"INITIAL SOLUTION FOR S-4: COURSE 265°, SPEED 8 KTS; RANGE 10000 YDS; D/E ANGLE CONFIRMS THAT TARGET IS ON SURFACE"		
[illegible]	▷	"GIVE ME A COURSE TO INTERCEPT TARGET, USING 10 KTS"					O	OBTAINS SOLUTION		
[illegible]	O						▷	"COURSE TO INTERCEPT: 322°, SPEED 10 KTS; TIME OF INTERCEPT: 1842"		
[illegible]	O				▷	"S-4 BRG 355°"	O			
26	▷	"RIGHT 10° RUDDER; STEADY ON 322°"	O	PLACES RUDDER RIGHT 10°; STEADIES ON COURSE 322°	O		O		O	
	▷	"ALL-AHEAD 2/3; MAKE TURNS FOR 10 KTS"	O	RINGS UP ALL-AHEAD 2/3; ORDERS TURNS FOR 10 KTS	O		O	MONITORS NEW OWN-SHIP INPUTS	O	
[illegible]	O				▷	"S-4 BRG 354°, MODERATE CAVITATION"	O			

TABLE 8-3 (CONT)
ON-STATION PATROL

TIME	COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS	
[illegible]	▷	"ADVISE ME WHEN CONTACT RANGE IS [illegible]000 YDS"					○			
[illegible]	○				▷	"S-[illegible] BRG 353[illegible]"	○	CONTINUES TO UP-DATE SOLUTION		
[illegible]	○				▷	"S-4 BRG 354°, CLOSING"	○			
[illegible]	○				▷	"S-4 BRG 353°, TURN COUNT 64, CAVITATING"	○			
[illegible]	○						▷	"ESTIMATE CONTACT RANGE, 6000 YDS: PRESENT SOLUTION: COURSE 251°, SPEED [illegible] KTS"		
35	▷	"[illegible]-AHEAD 1/3"	○	RINGS UP ALL-AHEAD 1/3	○		○		○	
[illegible]	▷	"100 FT"	□	PLANES TO 100 FT					○	
36	○				▷	"S-4 BRG 352°"	○			
37	▷	"RIGHT 20° RUDDER; STEADY ON 000°"	○	PLACES RUDDER RIGHT 20°, STEADIES ON COURSE 000°	○		○		○	
	>	"SONAR, SWINGING SHIP; SEARCH THE BAFFLES"			○					

TABLE 8-3 (CONT)
ON-STATION PATROL

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
[illegible]	▷	"LEFT FULL RUDDER; STEADY ON 292°"	○	PLACES RUDDER LEFT FULL; STEADIES ON COURSE 292°	□	COMMENCES SEARCHING BAFFLES			○	
40	○				▷	"NO ADDITIONAL CONTACTS"	○			
41	▷	"70 FT"	○	PLANES TO 70 FT					○	
43	▷	"LOOK AROUND"	○				○	SELECTS PERISCOPE AS SENSOR INPUT		
	○				▷	"S-4 BRG 353°"	○			
	□	RAISES PERISCOPE; MAKES 360° SEARCH; TRAINS ON TARGET, PRESSES BEARING-MARK SWITCH, LOWERS PERISCOPE	□	COMPENSATES AS NECESSARY			□	MONITORS PERISCOPE BEARING INPUT		
	▷	"NO OTHER CONTACTS; TARGET IS A MERCHANT FREIGHTER; ANGLE ON THE BOW, PORT 45°"			○		○		○	
[illegible]	○				▷	"NO ADDITIONAL CONTACTS; S-4 BRG 353°"	○			
46	▷	"68 FT"	○	PLANES UP TO 68 FT					○	
47	▷	"OBSERVATION"	○				○			

TABLE 8-3 (CONT)
ON-STATION PATROL

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
	□	RAISES PERISCOPE; TRAINS ON TARGET, DEPRESSES BEARING-MARK SWITCH; ADJUSTS STADIMETER; DEPRESSES RANGE-MARK SWITCH; NOTES NATIONALITY OF VESSEL; LOWERS PERISCOPE	□	MAINTAINS DEPTH WITHIN 6 INCHES OF ORDERED DEPTH			□	MONITORS BEARING AND RANGE INPUTS FROM PERISCOPE; COMPARES THESE WITH GENERATED VALUES; MAKE ADJUSTMENTS AS NECESSARY		
[illegible]	▷	"TARGET IS A XXX FREIGHTER; ANGLE-ON-BOW PORT 70"			○		○	COMPARES ESTIMATED ANGLE-ON-THE BOW WITH GENERATED AOB		
[illegible]	▷	"200 FT"	○	PLANES DOWN TO 200 FT					○	
50	○				▷	"NO ADDITIONAL CONTACTS; S-4 BRG 350°"	○			
51	▷	"SECURE THE APPROACH; NAVIGATOR, GIVE ME A COURSE TO ORIGINAL TRACK"					○	SECURES APPROACH	○	DETERMINES COURSE TO RESUME PRESCRIBED SEARCH PATTERN
53	○								▷	"RECOMMEND 072°"
54	▷	"RIGHT 20° RUDDER; STEADY ON 072°"	○	PLACES RUDDER RIGHT 20° STEADIES ON COURSE 072°					○	
	▷	"SECURE THE TRACKING PARTY"			○	TRACKING PARTY SECURES	○	TRACKING PARTY CLEARS CONSOLE OF S-4 INPUTS AND SECURES		

TABLE 8-3 (CONT)
ON-STATION PATROL

TIME	COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS	
[illegible]	○								△	"NEXT SCHEDULED FLEET BROADCAST: 15 MINUTES; RECOMMEND NAVIGATIONAL FIX"
	○								△	"ENGINEERING REQUESTS PERMISSION TO BLOW DOWN BOILERS"
	△	"STANDBY THE RADIO, LORAN AND ECM; ECM, SEARCH ALL BANDS"							○	STANDS BY EQUIPMENT
[illegible]	△	"MAKE READY TO BLOW DOWN BOILERS, DUMP GARBAGE, AND PUMP BILGES							○	RELAYS ORDER TO ENGINEERING SPACES
[illegible]	△	"MAKE YOUR DEPTH 100 FT"	○	PLANES TO 100 FT					○	
[illegible]	△	"SONAR, SWINGING SHIP; SEARCH THE BAFFLES"			○					
	△	"LEFT 15° RUDDER; STEADY ON 040°"	○	PLACES RUDDER LEFT 15°; STEADIES ON COURSE 040°	○				○	
	○				△	"NO CONTACTS"				
[illegible]73	△	"RIGHT 20° RUDDER; STEADY ON 110°"	○	PLACES RUDDER RIGHT 20°; STEADIES ON COURSE 110°	○				○	
	○				△	"NO CONTACTS"				

TABLE 8-3 (CONT)
ON-STATION PATROL

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
275	▷	"LEFT 15° RUDDER; STEADY ON 060°"	○	PLACES RUDDER LEFT 15°; STEADIES ON COURSE 060°					○	
277	▷	"70 FT"	○	PLANES TO 70 FT					○	
278	▷	"LOOK AROUND"	○						○	
279	□	RAISES PERISCOPE, MAKES 360° SEARCH								
280	▷	"64 FT"	○	PLANES TO 64 FT					○	
282	▷	"RAISE THE MASTS"							○	RAISES MASTS, BEGINS RADIO, LORAN, AND ECM OPERATIONS
284	○								▷	"ECM CONTACT BEARING 050°; AIRCRAFT RADAR, FAINT SIGNAL"
	▷	"DOWN ALL MASTS; 700 FT, 25° DOWN BUBBLE; ALL-AHEAD FULL"	○	ASSUMES 25° DOWN BUBBLE AND PLANES TO 700 FT; RINGS UP ALL-AHEAD FULL.					○	LOWERS ALL MASTS
287	○		▷	"STEADY ON 700 FT"						
288	▷	"ALL-AHEAD 1/3; SONAR, LISTEN FOR SONOBUOYS"	○	RINGS UP ALL-AHEAD 1/3	○	LISTENS FOR SONOBUOYS			○	
290	○				▷	"NO CONTACTS"				

TABLE 8-3 (CONT)
ON-STATION PATROL

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
[illegible]	O								Δ	"NEXT FLEET BROADCAST SCHEDULED FOR 0300"
	Δ	"STANDBY THE ECM, LORAN, AND RADIO; ECM, SE[illegible] [illegible]"							O	STANDS BY RADIO, LORAN, AND ECM EQUIPMENTS
	Δ	"MAKE ALL PREPARATIONS TO PUMP BILGES, BLOW SANITARY [illegible], [illegible] BOILERS"							O	ADVISES ENGINEERING TO MAKE NECESSARY PREPARATIONS
[illegible]	Δ	"[illegible] FT"	O	PLANES TO 100 FT					O	
[illegible]	Δ	"SONAR, SWINGING SHIP; SEARCH THE BAFFLES"			O					
[illegible]	Δ	"LEFT FULL RUDDER; STEADY ON [illegible]"	O	PLACES RUDDER LEFT FULL; STEADIES ON COURSE 0[illegible]5	O				O	
[illegible]	O				Δ	"NO CONTACTS"				
3[illegible]	Δ	"[illegible] YOUR DEPTH TO [illegible] FT"	O	PLANES TO 70 FT					O	
[illegible]	Δ	"LOOK AROUND"					O			
	□	RAISES PERISCOPE AND MAKES FULL SEARCH	□	COMPENSATES AS REQUIRED						
[illegible]00	Δ	"63 FT"	O	PLANES TO 6[illegible] FT					O	

TABLE 8-3 (CONT)
ON-STATION PATROL

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
402	▷	"RAISE THE MASTS"							○	RAISES NECESSARY MASTS; BEGINS RADIO, LORAN, AND ECM OPERATIONS
404	○								▷	"NO ECM CONTACTS"
405	▷	"COMMENCE PUMPING BILGES; COMMENCE EJECTING GARBAGE"							○	RELAYS ORDER TO EJECT GARBAGE AND PUMP BILGES
407	▷	"COMMENCE BLOWING DOWN BOILERS"							○	ADVISES ENGINEERING TO COMMENCE BLOWING BOILERS
[illegible]	○								▷	"ZBO MESSAGE INDICATES NO TRAFFIC THIS SHIP"
[illegible]	○								▷	"BOILER BLOWING COMPLETED"
[illegible]	○								▷	"THE GDU HAS BEEN SECURED AND ALL BILGES ARE DR."
416	○		▷	"LOST AUTOMATIC CONTROL"						
	○				▷	"POWER FAILURE IN SONAR - ALL PASSIVE SYSTEMS OUT OF COMMISSION"				
	○						▷	"LOSS OF POWER TO AUTOMATIC COURSE COMPUTER"		
[illegible]	▷	"SHIFT TO EMERGENCY STEERING AND PLANES; MAKE YOUR DEPTH 350 FT"	○	SHIFTS TO EMERGENCY MODE; PLANES TO 350 FT					○	
	▷	"LOWER ALL MASTS"							○	LOWER ALL MASTS

TABLE 8-3 (CONT)
ON-STATION PATROL

TIME	COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS	
	□ ○	LOWERS PERISCOPE							△	"ENGINEERING REPORTS LOSS OF POWER TO OPERATIONS DISTRIBUTION FEEDER PANELS"
	△	"HAVE THE ENGINEER OFFICER REPORT AS SOON AS THE FAILURE HAS BEEN ISOLATED"							○	RELAYS WORD TO ENGINEERING SPACES
[illegible]	○								△	"ENGINEERING REPORTS FULL POWER RESTORED"
[illegible]	△	"SHIFT TO PRIMARY MODE"	○	SHIFTS PLANES AND RUDDER TO PRIMARY MODE						
[illegible]	○				△	"SONAR BACK ON THE LINE AND SEARCHING"	○			
	○						△	"FIRE CONTROL ON THE LINE"		
[illegible]	○				△	"NOISE LEVEL BRG 325°, SPOKING ON PASSIVE SONAR; MACHINERY NOISE, POSSIBLE SUBMARINE, LIGHT CAVITATION, HIGH BEARING DRIFT"	○			
	△	"LEFT FULL RUDDER; STEADY ON 325°"	○	PLACES RUDDER LEFT FULL, STEADIES ON COURSE 325°	○		○		○	

TABLE 8-3 (CONT)
ON-STATION PATROL

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
	△	"SNAPSHOT, SNAPSHOT, MAKE READY THE READY TUBES IN ALL RESPECTS"					○	ORDERS TUBES #1 AND #4 MADE READY IN ALL RESPECTS		
	○				△	"CONTACT BEARING 328° IDENTIFIED AS SUBMARINE; BEARING DRIFTING RIGHT, DESIGNATE S-7; GOOD BEARING	○			
							□	INSERTS PRE-SET FUNCTIONS FOR SNAPSHOT SITUATION		
	○				△	"ESTIMATE RANGE LESS THAN TWO MILES"	○			
	△	"USE DEFLECTION ANGLES OF 5° AND 15°; SET RUNNING DEPTH AT 100 FT AND 300 FT; SET ENABLING RUNS AT 1000 YDS"					○	INSERTS DEFLECTION ANGLES, RUNNING DEPTH, AND ENABLING RUN		
[illegible]	△	"RIGHT 10° RUDDER; STEADY ON 345°"	○	PLACES RUDDER RIGHT 10°, STEADIES ON COURSE 345°	○		○		○	
	○				△	"CONTACT S-7 BRG 334° STILL CAVITATING, MAKING 75 TURNS, ESTIMATE SPEED 9 KTS; TARGET IS ABOVE US"	○			
	○						△	"TUBES #1 AND #4 READY IN ALL RESPECTS"		

TABLE 8-2 (CONT)
ON-STATION PATROL

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
	▷	"STANDBY #1 AND #4"					O	PLACE TUBES #1 AND #4 STANDBY SWITCHES IN STANDBY		
[illegible]	▷	"SHOOT"					O	DEPRESSES FIRING KEY FOR TUBE #1		
	O						▷	"TUBE #1 FIRED ELECTRICALLY"		
							□	NOTES TIME OF FIRING		
[illegible]	▷	"SHOOT"					O	DEPRESSES FIRING KEY FOR TUBE #4		
	O						▷	"TUBE #4 FIRED ELECTRICALLY"		
	▷	"900 FT"	O	PLANES TO 900 FT			□	NOTES TIME OF FIRING	O	
	▷	"MAN BATTLE STATIONS"	O	MANS BATTLE STATIONS	O	MANS BATTLE STATIONS	O	MANS BATTLE STATIONS	O	MANS BATTLE STATIONS
	▷	"SONAR, FOLLOW THE TORPEDOES"			O	SONAR BEGINS TRACKING TORPEDOES				
	O				▷	"TORPEDOES BRG 000° AND 007°"	O			
428	▷	"GET A FIRE CONTROL SOLUTION"					O	INSERTS SPEED AND RANGE ESTIMATES		
	O				▷	"CONTACT BRG 354°, STILL CAVITATING, SPEED UNCHANGED AT 9 KTS"	O	INSERTS DATA INTO ANALYZER		

TABLE 8-3 (CONT)
ON-STATION PATROL

TIME		COMMAND	SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
	O					Δ	"TARGET RANGE ESTIMATED 3500 YDS, SPEED 9 KTS, COURSE 100°"		
[illegible]	Δ	"RELOAD #1 AND #4 WITH MK 37 MOD 0 TORPEDOES"				O	ORDERS TUBES #1 AND #4 RELOADED WITH MK 37 MOD 0 TORPEDOES		
	O			Δ	"LOST CONTACT ON OUR TORPEDOES; LAST BEARINGS: 010° AND 018°"	O			
	Δ	"MAKE READY TUBES #2 AND #3 IN ALL RESPECTS"				O	ORDERS TUBES #2 AND #3 MADE READY IN ALL RESPECTS		
[illegible]	Δ	"WE WILL SHOOT A DEPTH SPREAD; SET #2 FOR 100 FT, #3 FOR 300 FT, ENABLING RUN 1500 YDS, HIGH SPEED, NO LIMIT, ACTIVE HOMING, SNAKE SEARCH"				O	INSERTS PRE-SET AND SYNCHRONOUS FUNCTIONS		
[illegible]	O			Δ	"CONTACT S-7 BRG 015°, RANGE OPENING; STILL CAVITATING"	O			
	O					Δ	"TUBES #2 AND #3 READY IN ALL RESPECTS"		
1432	O			Δ	"EXPLOSION BEARING 020°"	O		O	
1433	O			Δ	"HIGH BREAKING-UP NOISE, BRG 020°"	O		O	

TABLE 6-3 (CONT)
ON-STATION PATROL

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
									□	RECORDS POSITIONS OF SHIPS DURING PRECEDING ACTION, AND PROBABLE POSITION OF DESTROYED TARGET
[illegible]	▷	"SONAR, COMING RIGHT; SEARCH THE BAFFLES"			O					
	▷	"RIGHT [illegible] RUDDER; STEADY ON 100°"	O	PUTS RUDDER RIGHT 15°; STEADIES ON COURSE 100			O		O	
					□	BEGINS SEARCHING BAFFLES				
[illegible]	O				▷	"NO CONTACTS"	O			
[illegible]	▷	"[illegible]KE TUBES #1 AND [illegible] READY FOR S[illegible]APSHOT"					O	INSERTS PRE-SET FUNCTIONS FOR SNAPSHOT INTO BOTH TUBES		
	O						▷	"TUBES #1 AND [illegible], HAVE BEEN PLACED IN READY CONDITION"		
[illegible]	▷	"SONAR, SEARCH ALL AROUND"			O	SEARCHES ALL AROUND				
[illegible]	O				▷	"NO CONTACTS"				
[illegible]	▷	"MAKE YOUR DEPTH 300 FT"	O	PLANES TO 300 FT, COMPENSATING AS REQUIRED	O				O	

TABLE 8-3 (CONT)
ON-STATION PATROL

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
[illegible]	○				△	"NO CONTACTS"				
497	△	"SECURE ALL TUBES"					○	SECURES ALL TUBES		
[illegible]	△	"SECURE FROM BATTLE STATIONS"	○	SECURES FROM BATTLE STATIONS	○	SECURES FROM BATTLE STATIONS	○	SECURES FROM BATTLE STATIONS	○	SECURES FROM BATTLE STATIONS

8.5.4 ASW Action

At the beginning of this situation the submarine is patrolling its area on a course of 085°, speed five knots, and depth 500 feet. It holds no sonar contacts. Two tubes are ready in snapshot condition; remaining tubes are loaded but secured. All weapons are assumed to be torpedoes Mk 37 Mod 0, unless otherwise specified.

This situation describes the ASW action from the initial detection of an enemy submarine to the conclusion of the action.

The operational sequence is outlined in Table 8-4.

TABLE 8-3
ASW ACTION

TIME	COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS	
	o				▷	"POSSIBLE NOISE LEVEL BRG 025°"	o			
	▷	"MAKE TURNS FOR 3 KTS"	O	ORDERS TURNS FOR 3 KTS			□	PLACES F/C CONSOLE IN OPERATION; SELECTS APPROPRIATE SENSOR AS INPUT	o	
	o				▷	"NOISE LEVEL BRG 040°; WEAK AND INTERMITTENT"	O	MONITORS OWN SHIP AND TARGET INPUTS		
	▷	"LEFT 15° RUDDER; STEADY ON 050°"	O	PLACES RUDDER LEFT 15°; STEADIES ON COURSE 050°			o		o	
	o				▷	"LOST CONTACT ON NOISE LEVEL; LAST BRG 034°"	o			
	▷	"MAKE YOUR DEPTH 400 FT; RIG SHIP FOR QUIET CONDITION II"	O	PLANES TO 400 FT	o		o		O	PASSES WORD TO RIG SHIP FOR QUIET CONDITION II
	o				▷	"HAVE REGAINED CONTACT; BRG 035° INTERMITTENT; TRACKING MANUALLY"	o			

▷ INFORMATION TRANSMITTED
o INFORMATION ADDRESSEE
O ACTION ADDRESSEE
□ SELF-INITIATED ACTION

TABLE 8-4 (CONT)
ASW ACTION

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
10	△	"350 FT"	○	PLANES TO 350 FT			○		○	
	○				△	"CONTACT BRG 033°; NOISE LEVEL INCREASING: MACHINERY NOISE; DESIGNATE S-9"	○			
1[illegible]	△	"COME LEFT TO 030°; STATION THE TRACKING PARTY"	○	COMES LEFT TO COURSE 030°	○	TRACKING PARTY MANS STATIONS; ONE SUB-SYSTEM IS DIRECTED CONTINUOUSLY AT S-9; ANOTHER CONTINUES MAKING FULL SWEEPS	○	TRACKING PARTY MANS STATIONS: SELECTS METHOD OF TARGET ANALYSIS; CHECKS LATITUDE PROOFING AND FIRING DISPLAYS; DETERMINES SPEED CORRECTION, IF NECESSARY AND INSERTS INTO BALLISTIC PLUG	○	
	○								△	"SHIP RIGGED FOR QUIET CONDITION II"
							□	CHECKS TUBE-BALLISTIC SWITCHES; CONTINUOUSLY MONITORS BEARING INPUTS FROM SENSORS, AND OWN SHIP INPUTS FOR COURSE, SPEED, AND DEPTH		
13	△	"REQUEST RANGE ESTIMATE"			○		□	COMMENCES ANALYSIS OF TARGET BEARING DRIFT		
	○				△	"ESTIMATE RANGE OF S-9 OVER 10 MILES; BRG 032°"	○			
	△	"LEFT 15° RUDDER; STEADY ON 005°"	○	PLACES RUDDER LEFT 15°; STEADIES ON COURSE 005°			○		○	

TABLE C-4 (CONT)
ASW ACTION

TIME	COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS	
	○				▷	"S-9 BRG 031°; DEFINITE ENGINE NOISE"	○			
	▷	"LEFT [illegible]° RUDDER; STEADY ON 310°"	○	PLACES RUDDER LEFT 20°; STEADIES ON COURSE 310°			○		○	
	○						▷	"S-9 BRG DRIFT 1-1/2 DG LEFT"		
	▷	"RIGHT 15° RUDDER; STEADY ON 000°"	○	PLACES RUDDER RIGHT 15°; STEADIES ON COURSE 000°			□	CONTINUES ANALYSIS OF BEARING DRIFT	○	
	○				▷	"PAINT NOISE LEVEL BRG 218°"	○	SELECTS APPROPRIATE SENSOR FOR NEW MOTION ANALYSIS		
	○				▷	"S-9 BRG 023°; SLOW SPEED SCREWS"	○			
	○				▷	"NOISE LEVEL BRG 218° EVALUATED AS FISH"	○	CLEARS ANALYZER OF INPUTS		
	○						▷	"REQUEST COURSE CHANGE TO OBTAIN RANGE ESTIMATE"		
	▷	"LEFT FULL RUDDER; STEADY ON 315°"	○	PLACES RUDDER LEFT FULL; STEADIES ON COURSE 315°			○		○	

TABLE 8-4 (CONT)
ASW ACTION

TIME		COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
25	○				▷	"S-9 BRG 027°, LIGHT CAVITATION"	○			
							□	OBTAINS PRELIMINARY ESTIMATE OF TARGET RANGE; INSERTS RANGE INTO ANALYZER; ASSUMES TARGET SPEED OF 10 KTS, INSERTS SPEED INTO ANALYZER; OBTAINS INITIAL SOLUTION		
[illegible]	○						▷	"INITIAL SOLUTION: COURSE 240°; SPEED 10 KTS, RANGE 16,000 YDS"		
[illegible]	○				▷	"S-9 BRG 035°"	○			
[illegible]	▷	"RIGHT 15° RUDDER; STEADY ON 339°; ALL AHEAD 2/3; BUILD UP TURNS SLOWLY"	○	PLACES RUDDER RIGHT 15°; STEADIES ON COURSE 339°; RINGS UP ALL AHEAD 2/3; ORDERS TURNS BUILT UP SLOWLY			○		○	
	○				▷	"S-9 BRG 026"	□	NOTES FAILURE OF ANALYZER TO RECEIVE SONAR BEARING; INSERTS BEARING MANUALLY		
					○		▷	"SONAR, CHECK YOUR 'BEARING TRANSMITTER' CIRCUIT; LAST BEARING WAS NOT RECEIVED BY ANALYZER"		

TABLE 6-4 (CONT)
ASW ACTION

TIME	COMMAND	SHIP CONTROL	SONAR	FIRE CONTROL	OPERATIONS
			□ CHECKS BEARING TRANSMITTER CIRCUIT; DISCOVERS BLOWN FUSE, REPLACES		
			▷ "FAILURE IN BEARING TRANSMITTER HAS BEEN ISOLATED AND CORRECTED"	○	
	▷ "MAN BATTLE STATIONS"	○ MANS BATTLE STATIONS	○ MANS BATTLE STATIONS	○ MANS BATTLE STATIONS	○ MANS BATTLE STATIONS; MANS IC PHONE CIRCUITS; RECEIVES REPORTS FROM ALL STATIONS
	○		▷ "S-3 BRG [illegible]°"	○ EVALUATES ECCENTRIC BRG; DROPS FROM MOTION ANALYSIS	
	○		▷ "S-3 BRG 005°, LIGHT, SINGLE SCREW; TURN COUNT 65, ESTIMATE SPEED [illegible] KTS, LIGHT CAVITATION; PROBABLE SUBMARINE"	○ INSERTS NEW ESTIMATES OF TARGET SPEED; OBTAINS REVISED SOLUTION; INSERTS ESTIMATE OF TARGET LENGTH	
	○		○	▷ "PRESENT TARGET SOLUTION: COURSE 335°, SPEED [illegible] KTS, RANGE 35,500 YDS"	
	▷ "COME RIGHT TO 350°"	○ COMES RIGHT TO COURSE 350°		○	○

TABLE [illegible] CONT'
AS, ACTION

TIME		CONNING		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS
35	○								▷	"ALL STATIONS ON THE LINE; BATTLE STATIONS HAVE BEEN MANNED THROUGHOUT THE SHIP"
[illegible]	▷	"WE WILL FIRE [illegible] INITIAL [illegible] FIRING ORDER WILL BE [illegible]"					○	SETS MODE-OF-OPERATION SELECTOR SWITCH TO PRE-SET MODE; SETS IN FIRING ORDER		
36	○				▷	"TARGET BRG [illegible]"	○			
[illegible]	▷	"MAKE READY ALL TUBES WITH THE EXCEPTION OF OPENING THE OUTER DOORS"					○	ORDERS TUBES MADE READY WITH EXCEPTION OF OPENING THE OUTER DOORS		
[illegible]	○				▷	"TARGET BRG [illegible], STILL CAVITATING SLIGHTLY"	○	CONTINUES TO UP-DATE SOLUTION		
[illegible]	○						▷	"PRESENT TARGET SOLUTION: COURSE 22[illegible]°; SPEED [illegible] KTS, RANGE 10,500 YDS"		
[illegible]	▷	"ALL AHEAD 2/3; STEER [illegible]"	○	RINGS UP ALL AHEAD 2/3; STEERS COURSE 350			○		○	
[illegible]	▷	"USE FOLLOWING NON-SYNCHRONOUS FUNCTIONS: PASSIVE HOMING, LOW SPEED, SNAKE SEARCH, NO LIMITS"					○	INSERTS ORDERED NON-SYNCHRONOUS FUNCTIONS		

TABLE 8-4 (CONT)
ASW ACTION

TIME	COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS	
[illegible]	○				△	"TARGET BEARINGS ARE STEADY ON 024°; NO DISCERNABLE DRIFT; NOISE LEVEL INCREASING; TARGET APPEARS TO BE ABOVE US"	○			
	○						△	"PRESENT SOLUTION: COURSE 233°, SPEED 9 KTS, RANGE 8200 YDS; EVALUATE SOLUTION AS GOOD"		
45	△	"SET ENABLING RUNS FOR 1,000 YDS; SET RUNNING DEPTHS AT 100 AND 250 FT"					○	INSERTS ORDERED ENABLING RUNS AND RUNNING DEPTHS		
46	○				△	"S-9 BRG 024°"	○			
48	△	"OPEN THE OUTER DOORS ON #1 AND #4"					○	ORDERS OUTER DOORS OPEN ON #1 AND #4		
50	○						△	"TUBES #1 AND #4 READY IN ALL RESPECTS"		
51	○				△	"TARGET IS INCREASING SPEED; BRG 025°"	○			
52	○				△	"TARGET BRG 023°; TURN COUNT 102; HEAVY CAVITATION; ESTIMATE SPEED 13 KTS"	○	INSERTS NEW TARGET SPEED; OBTAINS NEW SOLUTION		
53	○				△	"TARGET IS DRAWING LEFT, NOW BEARS 021°; DE ANGLE +10°"	○	ESTIMATES TARGET DEPTH		

TABLE 8-4 (CONT)
ASW ACTION

TIME	CONN		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS	
[illegible]	O						▷	"TARGET COURSE STEADY ON 227°; ESTIMATE TARGET DEPTH AT 250 FT, TARGET RANGE AT 6100 YDS"		
[illegible]	O				▷	"TARGET BRG 018°, HEAVY CAVITATION; SPEED UNCHANGED"	O			
[illegible]	▷	"CHANGE TORPEDO SPEED SETTINGS TO HIGH"					O	INSERTS CHANGE IN TORPEDO SPEED SETTINGS		
58	▷	"STANDBY #1 AND #2"					O	ORDERS TORPEDOMEN TO STANDBY TUBES #1 AND #2		
[illegible]	▷	"GET A SINGLE PING RANGE"			O	OBTAINS RANGE TO TARGET WITH SINGLE PING	O			
	O				▷	"RANGE TO TARGET, 5800 YDS. BRG 015°"	O	INSERTS RANGE; OBTAINS FINAL CHECK ON SOLUTION		
	O						▷	"CORRECT SOLUTION"		
00	▷	"SHOOT"					O	DEPRESSES FIRING KEY: STARTS TIMER		
	O						▷	"FIRE #1 - - TUBE #1 FIRED ELECTRICALLY"		
	▷	"SHOOT"					O	DEPRESSES FIRING KEY: STARTS TIMER		

TABLE 8-4 (CONT)
ASW ACTION

TIME	COMMAND		SHIP CONTROL		SONAR		FIRE CONTROL		OPERATIONS	
	O						Δ	"FIRE #2 - - TUBE #2 FIRED ELECTRICALLY"		
61	Δ	"SONAR, FOLLOW THE TORPEDOES"			O	BEGINS TRACKING TORPEDOES				
	Δ	"MAKE TURNS FOR 2 KTS; RIG SHIP FOR QUIET CONDITION III"	O	ORDERS TURNS FOR 2 KTS			O		O	PASSES WORD TO RIG SHIP FOR QUIET CONDITION III
62	O				Δ	"TORPEDOES RUNNING AT 355° AND 346°; TARGET BRG 011°"	O			
	Δ	"RELOAD #1 AND #2 WITH EX 10 AND MK 37-1					O	ORDERS TORPEDOES RELOADED INTO TUBES #1 AND #2		
63	O				Δ	"TORPEDOES RUNNING AT 356° AND 347°, VERY FAINT, TARGET BRG 007° STILL CAVITATING	O			
	O						Δ	"CONTACT STEADY ON COURSE 227°; ESTIMATE DEPTH 270 FT, RANGE 5700 YDS"		
64	O				Δ	"LOST CONTACT ON TORPEDOES; LAST BRGS 357° AND 345°; TARGET NOW BEARS 004°	O			

TABLE 8.4 (CONT)
ASW ACTION

TIME	COMMAND	SHIP CONTROL	SONAR	FIRE CONTROL	OPERATIONS
[illegible]	○		△ "TARGET HAS DECREASED SPEED; NO LONGER CAVITATING; TURN COUNT 4? RPM; ESTIMATE SPEED 5 KTS"	○ INSERTS NEW DATA	
[illegible]	○			△ "WEAPONS SHOULD BE WITHIN ACQUISITION RANGE"	
[illegible]	○		△ "TARGET IS INCREASING SPEED AGAIN; HEAVY CAVITATION; BRG 002"	○	
[illegible]	○		△ "SINGLE EXPLOSION ON LAST TARGET BEARING"	○	
	○			△ "TIME ANALYSIS INDICATES FIRST TORPEDO HIT TARGET"	
	○		△ "BREAKING UP NOISES BRG 001"	○	
[illegible]	△ "RIGHT FULL RUDDER; STEADY ON 175; SONAR, SEARCH ALL AROUND"	○ PLACES RUDDER RIGHT FULL; STEADIES ON 175	○	○	○
			□ SEARCHES ALL AROUND		
[illegible]	○		△ "COMPLETE SWEEP ALL AROUND; NO CONTACTS"	○	
[illegible]	△ "SECURE ALL TUBES; SECURE FROM BATTLE STATIONS"	○ SECURES FROM BATTLE STATIONS	○ SECURES FROM BATTLE STATIONS	○ ORDERS ALL TUBES SECURED; SECURES FROM BATTLE STATIONS	○ ORDERS IC CIRCUITS SECURED; SECURES FROM BATTLE STATION

8.6 OPERATIONAL SEQUENCE TESTS OF PANEL-FACE LAYOUTS

8.6.1 Ship Control Operational Sequence Test of Console Feasibility

8.6.1.1 Getting Underway

Time		Ship Control	Activity
0	O*	Mans Stations	1) operator sits down at console 2) requests Maintenance Monitoring Station to turn on power to controls and indicators
9	□	Tests steering systems and rudder angle indicator	1) positions Steering Mode Selector on Secondary 2) moves joystick to various positions and observes corresponding movement on rudder angle indicator 3) positions Steering Mode Selector on Tertiary 4) removes emergency helm and repeats (2)
10	□	Tests annunciators	1) informs maneuvering room via speaker that annunciators are being tested 2) sets annunciator to various speeds 3) monitors compliance
	□	Tests Main Induction Valve	Performed at Monitoring Station
12	▷	Requests permission to test screw or turbines and propulsion motor	Not performed at Ship Control Station (S.C.)
13	O	Tests screw	Not performed at S.C.
	□	Checks air cut into whistle	Not performed at S.C.
	O	Orders Maneuvering to Standby	Communicates order via speaker mike

* O ACTION ADDRESSEE
□ SELF-INITIATED ACTION
▷ INFORMATION TRANSMITTED
O INFORMATION ADDRESSEE

Time		Ship Control	Activity
	O	Puts rudder amidships	1) steering mode selector set at Secondary 2) SQUIRE is set for TV periscope 3) joystick is moved to amidships position
30	O	Rings up all back 1/3	1) positions annunciator to back 1/3 2) observes maneuvering room answer on annunciator
	O	Puts rudder right full	Moves joystick control to right full rudder position
31	O	Rings up all stop; shifts rudder to left full	1) positions annunciator to all stop 2) monitors compliance 3) moves joystick to left full rudder position
	O	Rings up all ahead 2/3	1) positions annunciator to ahead 2/3 2) monitors compliance
33	O	Rings up all stop and all back 2/3	1) positions annunciator to all stop 2) monitors compliance 3) repeats 1) and 2) for all back 2/3
	O	Shifts rudder to right full	Moves joystick to right full rudder position
35	O	Rings up all stop; shifts rudder to left full	1) positions annunciator to all stop 2) monitors compliance 3) moves joystick to left full position
	O	Rings up all ahead 2/3	1) positions annunciator to ahead 2/3 2) monitors compliance
37	O	Checks the swing	1) moves joystick to reduce rudder angle 2) monitors gyro repeater
	O	Steadies up on 170°	1) positions joystick to reduce turn rate to zero at 170°

Time		Ship Control	Activity
38	○	Rings up all ahead 1/3	1) positions annunciator to ahead 1/3 2) monitors compliance
42	○	Changes course to 174°	1) positions joystick to change course 2) monitors gyro repeater
44	○	Continues swing to 177°	Repeats 1) and 2) above
		Allows no deviation to left of 177°	1) monitors gyro repeater 2) moves joystick to right when necessary
46	○	Rings up all ahead 2/3	1) positions annunciator to ahead 2/3 2) monitors compliance
	○	Changes course to 171°	1) moves joystick to change course 2) monitors gyro repeater 3) moves joystick to reduce turn rate at 171°
50	○	Rings up 67 rpm	1) calls down 67 rpm 2) monitors compliance on rpm indicator
55	○	Changes course to 168°	1) moves joystick to change course 2) monitors gyro repeater 3) moves joystick to reduce turn rate to zero at 168°
64	○	Sets regular sea detail	No change made in station complement
65	○	Rings up all ahead standard	1) positions annunciator to ahead standard 2) monitors compliance
71	○	Changes course to 162°	1) moves joystick to change course 2) monitors gyro repeater 3) moves joystick to reduce turn rate to zero at 162°
	▷	"Request permission to test planes and bridge hatches"	Verbally requests permission of Command or O.O.D.

Time		Ship Control	Activity
	○	Tests planes and hatches	1) hatches are checked locally, individual indicators are monitored at Monitoring; critical indicators are monitored at Ship Control 2) positions Diving Mode Selector on Secondary 3) moves joystick to various positions and observes movement on stern and fairwater planes indicators
	▷	"Request permission to test blowing of tanks"	Verbally requests permission of Command or O.O.D.
	○	Tests air to MBTs	1) monitoring station operator connects air bank to blower system 2) S.C. operator observes air supply indicator for adequacy (green) 3) moves dual lever-in-groove controls back and activates blower 4) monitors indication of blower on
84	○	Puts rudder left 15°; steadies on course 110°	1) moves joystick until rudder angle indicator shows 15° left rudder 2) monitors gyro repeater 3) moves joystick to reduce turn rate to zero at 110°
	○	Receives "Rigged For Dive" reports from all compartments	Checks summary indicators at console; Monitoring operator also checks his indicators
	□	Insures that ship is properly compensated	1) checks to see if ship properly compensated (water levels in trim tanks) for diving 2) makes adjustment in water levels if necessary
127	▷	"Ship rigged for dive and compensated"	Reports ship secured for submerging

8.6.1.2 Transit

Time		Ship Control	Activity
0	⬡	Opens all main vents; shuts ventilation exhaust velves; shuts outboard induction valve; puts rudder amidships; rings up all ahead 2/3, tests planes	1) vents opened using dual lever-in-groove controls 2) ventilation exhaust and outboard induction valves shut at Monitoring (M.C.) indicators monitored at Ship Control (S.C.) 3) moves joystick to amidships position 4) positions annunciator to ahead 2/3 5) monitors compliance 6) positions Diving Mode Selector to Secondary 7) moves joystick to various positions and observes movement on fairwater and stern planes indicators In addition, the operator would perform the following prior to diving 8) positions the Display Selector to On 9) set a maximum rudder angle and maximum pitch angle 10) set the Depth Scale Selector to shallow 11) set the Planes Ratio Selector to some position 12) set a gain (fine or course) for SQUIRE 13) position the Trim Mode Selector to Secondary
	▷	"Straight Board"	Verbal report to Command that ship is rigged for dive
	▷	"Planes working satisfactorily"	Verbal report to Command that planes are functioning properly
1	◯	Planes toward ordered depth	1) enters ordered depth via keyboard to position ordered symbol on SQUIRE 2) moves joystick forward initiating dive

Time	Ship Control		Activity
	□	Shuts all main vents (when passing 45 ft)	1) moves dual lever-in-groove controls back to neutral position to close vents
	▷	"All vents shut"	Verbal report to Command
2	□	Proceeds to ordered depth	1) positions quickened symbol on ordered symbol; holds until actual symbol is superimposed on ordered symbol 2) sets Gain Selector to "Fine" position
3	○	Rings up all ahead 1/3	Procedure described previously
4	▷	"Permission to cycle the vents"	Verbal request of Command
	○	Cycles the vents	Opens forward and after MBT tank group vents separately using lever-in-groove controls; closes vents after cycling
	□	Manipulates trim controls to obtain satisfactory trim	Depresses the trim correct button; tanks adjustment accomplished automatically
12	▷	"Steady on 110 ft; trim satisfactory"	Verbal report to Command
	□	Shifts to automatic maneuvering control	1) positions Steering Mode Selector on Primary 2) positions Diving Mode Selector on Primary 3) checks Neutral Angle Selector for 0° setting
14	○	Rings up all ahead full; Dive at 10° to ordered depth	1) positions annunciator 2) monitors compliance 3) sets Pitch Selector to 10° 4) enters 200 ft in keyboard 5) monitors SQUIRE
	▷	"Steady on 200 ft"	Verbal report to Command
31	▷	"Gyro Failure, Gyro Failure"	Verbal report to Command

Time	Ship Control	Activity
○	Shifts from automatic to manual control	1) To hold course, operator switches to automatic maneuvering; sets mean course control to 110°. 2) Steering Mode Selector set to Secondary 3) Joystick moved to hold course; automatic control of depth
35 ○	Compares SINS heading with new repeater heading; when coincidental, shifts back to automatic control	Steering Mode Selector set to Primary
36 ▷	"Repeater back on the line; have shifted to automatic control"	Verbal report to command

Time	Ship Control	Activity
1600 ○	Rings up all ahead 1/3	Procedure described previously
○	Planes to 100 ft	Same as above
○	Places rudder right 10°; comes to course 270°	1) sets Rudder Selector to 10° 2) enters 270° Right to position ordered symbol 3) drives quickened symbol to ordered symbol via joystick
▷	"Steady on 270°"	Verbal report to Command
1609 ○	Places rudder right 10°; comes to course 090°	Course-changing maneuver described previously
1610 ○	Raises induction mast; checks negative flood shut; opens negative vent; opens induction drain to negative tank	1) performed at Monitoring Station 2) observes negative flood indicator 3) positions lever-lock switch to open 4) performed at Monitoring Station
1621 ○	Planes up to 70 ft	Depth-changing maneuver described previously
1622 ▷	"Steady on 70 ft"	Verbal report to Command
1623 □	Compensates as necessary	If necessary, that is, when criticality indicators show need for compensation, trim correct button is depressed with water being expelled from aux. tanks in usual case

Time		Ship Control	Activity
1625	○	Planes up to 64 ft	Maneuver described previously
1627	○	Planes up to 62 ft	Same as above
1628	□	Compensates as necessary	Described previously
1630	▷	"Rigged to ventilate; trim satisfactory"	Verbal reports to Command from Monitoring and Ship Control
1631	○	Opens induction and ventilation exhaust valves; starts low pressure blowers; starts induction booster fans	1) order for blowers relayed via Ship Control; all other task aspects performed at Monitoring Station
1640	□	Compensates for pumping as necessary	Trim correct button is depressed to effect compensation
1685	○	Secures the low pressure blower; shuts the induction and ventilation exhaust valves; shuts induction mast drains to negative tank; lowers induction mast; secures the induction booster fans; shuts negative vent	1) order to secure blower relayed via Ship Control 2) vent shut at station; all other task aspects performed at Monitoring Station
1694	▷	"Secured from ventilating"	Verbal report to Command
1695	□	Compensates as necessary	Described previously
1696	○	Planes down to 200 ft	Maneuver described previously

8.6.1.3 On-Station Patrol

Time		Ship Control	Activity
5	○	Places rudder left 15°; steadies on 000°	With Diving Mode and Steering Mode Selectors set at Primary 1) max. rudder selector is set at 15° 2) 000 is entered via keyboard 3) SQUIRE is monitored

Time		Ship Control	Activity
9	○	Orders turns for 3 kts	1) order relayed via speaker 2) order is acknowledged verbally 3) knots indicator monitored
16	○	Places rudder left 15°; steadies on course 270°	Procedure described previously
26	○	Places rudder right 10°; steadies on course 322°	Procedure described previously
		Rings up all-ahead 2/3; orders turn for 10 kts	Both procedures described previously
35	○	Rings up all ahead 1/3	Procedure described previously
36	○	Planes to 100 ft	1) enters 100 ft via keyboard 2) monitors SQUIRE
37	○	Places rudder right 20°; steadies on course 000°	Procedure described previously
39	○	Places rudder left full; steadies on course 292°	Procedure described previously
41	○	Planes to 70 ft	Procedure described previously
46	○	Planes to 68 ft	Same as above
	□	Maintains Depth within 6 inches of ordered depth	1) sets gain control to "fine" position 2) monitors SQUIRE
49	○	Planes down to 200 ft	Procedure described previously
54	○	Places rudder right 20°; steadies on course 072°	Procedure described previously
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268	○	Planes to 100 ft	Procedure described previously
		Places rudder left 15°; steadies on course 040°	Procedure described previously
273	○	Places rudder right 20°; steadies on course 110°	Same as above

Time		Ship Control	Activity
275	○	Places rudder left 15°; steadies on course 060°	Same as above
277	○	Planes to 70 ft	Procedure described previously
280	○	Planes to 64 ft	Same as above
	○	Assumes 25° down bubble and planes to 700 ft; rings up all-ahead 2/3	If speed is essential, 1) override control is depressed and joystick moved to dive position to drive quickened symbol 2) pitch selector set to 25° 3) annunciator set to all-ahead 2/3 4) 700 ft entered via keyboard to position ordered symbol 5) joystick can be centered to allow automatic control system to take over
287	▷	"Steady on 700 ft"	Verbal report to Command
288	○	Rings up all-ahead 1/3	Procedure described previously
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385	○	Planes to 100 ft	Procedure described previously
392	○	Places rudder left full; steadies on course 085°	Procedure described previously
397	○	Planes to 70 ft	Procedure described previously
399	□	Compensates as required	Trim correct button depressed, trim imbalance corrected automatically
400	○	Planes to 63 ft	Procedure described previously
418	▷	"Lost automatic control"	Verbal report to Command
418	○	Shifts to emergency mode; planes to 200 ft	1) status mode panel indicators will direct operator's behavior; if failure is complete, Diving and Steering Mode Selectors are set to Tertiary and second operator takes emergency helm (rudder) 2) ship control operator planes to ordered depth while second operator holds course

Time		Ship Control	Activity
423	○	Shifts planes and rudder to primary mode	1) both mode selectors set to Primary and wheel is deactivated 2) new depth is entered via keyboard
	○	Places rudder left full; steadies on course 325°	Procedure described previously
426	○	Places rudder right 10°; steadies on course 345°	Procedure described previously
	□	Mans battle stations	1) Steering and Diving Mode Selectors set at Secondary 2) second operator stands by
	○	Puts rudder right 15°; steadies on course 100°	1) sets Rudder Selector to 15° 2) enters 100° via keyboard 3) moves joystick to come to ordered course
493	○	Planes to 300 ft, compensating as required	1) checks or changes Pitch Selector Setting 2) enters 300 ft via keyboard 3) moves joystick to come to ordered depth 4) depress trim correct button if necessary
498	○	Secures from battle stations	1) sets Mode Selectors to Primary 2) second operator leaves station

8.6.1.4 ASW Action

1	○	Orders turns for 3 kts	Relays order via speaker mike
3	○	Places rudder left 15°; steadies on course 050°	1) sets Rudder Selector to 15° 2) enters 050° via keyboard 3) in Secondary, drives quickened symbol via joystick
4	○	Planes to 400 ft	1) sets Pitch Selector to appropriate setting 2) enters 400 ft via keyboard 3) drives quickened symbol via joystick
10	○	Planes to 350 ft	Procedure described previously

Time		Ship Control	Activity
12	○	Comes left to course 030°	Procedure described previously
	○	Places rudder left 15°; steadies on course 005°	To obtain Fine Control, Gain Mode Selector is set to "fine"
18	○	Places rudder left 20°; steadies on course 310°	Procedure described previously
21	○	Places rudder left 15°; steadies on course 000°	Same as above
	○	Places rudder left full; steadies on course 315°	Same as above
28	○	Places rudder right 15°; steadies on course 339°; rings up all ahead 2/3; orders turns built up slowly	1) procedure for changing course described previously 2) sets annunciator to ahead 2/3 3) monitors compliance 4) relays order for slow build-up via speaker mike 5) monitors cavitation indicators
	□	Mans battle stations	Second operator stands by at station console
	○	Comes right to 350°	Procedure described previously
40	○	Rings up all ahead 1/3; steers course 354°	Both procedures described previously
		Orders turns for 2 kts	Order relayed via speaker mike
70	○	Places rudder right full; steadies on 175°	Procedure described previously
74	○	Secures from battle stations	1) second operator leaves station 2) Steering and Diving Mode Selectors can be set to Primary

8.6.2 Sonar Surveillance Operational Sequence Test of Console Feasibility

An operational sequence test was conducted in order to evaluate the feasibility of the sonar surveillance console. The test involved tabulating the methods employed by sonar operators in carrying out the tasks indicated in the operational sequence. The feasibility under four conditions was examined. These conditions were: 1) Getting Underway; 2) Transiting; 3) Patrolling On Station; 4) ASW Action. A comparison of the required activities and the capability for such activities provided by panel face controls and displays indicated that the console was operationally feasible.

8.6.2.1 Getting Underway

Time		Sonar
00 ○	Mans Stations	Sonar initial detection operator and supervisor man sonar stations. Supervisor mans frequency monitoring station. He monitors classification station at intervals.
09 □	Tests and Checks Sonar Systems	Sonar operator and supervisor turn on, check, and test all sonar surveillance equipment: initial detection, frequency monitoring, tracking (active and passive), and classification.
57 □	Commences Searching Forward of Beams	Initial detection sonar operator commences monitoring main display; only reports contacts forward of the beam. Observes main CRT display (bearing vs amplitude), bearing time recorder (BTR), and listens to audio signals through earphones while training audio beam manually. Operator at frequency monitoring station also observes Demon and BSM displays.

Time		Sonar	
58	▷	"No Contacts Other Than Surface Ship Off Starboard Bow"	Sonar initial detection operator reports on only contact he has detected; surface ship off starboard bow. Ship was detected on CRT.
61	Ȯ	Commences Full Search	Sonar initial detection operator concentrates searching on full 360°.
64	○	Sets Reg. Sea Detail; Continues Full, Continuous Sweep With Sonar	Maneuvering watch sonar operator is relieved by regular section watch operator. Maneuvering watch operator passes on instructions to continue conducting full search using both aural and visual displays. After conducting search, reports "no additional contacts."
	▷	"No Additional Contacts"	

▷ Information Transmitted

○ Information Addressee

Ȯ Action Addressee

□ Self-initiated Action

8.6.2.2 Transit

Time		Sonar	
02	▷	"No Contacts"	After diving and reaching ordered depth, sonar initial detection operator monitors main CRT and conducts aural search in azimuth at various depression and elevation angles. Reports "no contacts."

Time		Sonar
20	▷ "Biological Noise Bearing 164°"	From aural display (earphones), sonar operator detects a noise in the water bearing 164° true. Immediately after detecting it, he identifies it as a biological noise (fish, shrimp, whale, etc.). This evaluation was made on the basis of aural information received over the earphones.
1608	▷ "No Contacts"	After a change in ship's depth and course, the sonar operator again conducts a full search (aural and visual) and reports "no contacts."
1651	▷ "Possible Noise Level Bearing 320°"	Sonar operator has detected noise in the water bearing 320° true. Has not been able to confirm that it is not ambient. This possible noise was detected on both visual (CRT) and aural (earphones) displays.
1654	▷ "Contact Bearing 320° Evaluated as Fish"	Utilizing both earphones and frequency monitoring recorders, the sonar supervisor has evaluated the contact at 320° as fish.

8.6.2.3 On-Station Patrol

00	▷ "Faint Noise Level, BRG 010°"	Sonar initial detection operator has detected a possible target bearing 010°. Detection was made on main initial detection (I.D.) CRT, broad band sweep.
02	▷ "Noise Level Brg 009°, Weak and Intermittent"	Initial detection operator reports possible contact bears 009° as determined on selected fixed band-pass sweep of main I.D. CRT.
04	▷ "Noise Level Brg 005°"	Contact now bears 005° true as determined by further refinement of D/E angle, frequency, and audio signal level at initial detection station.

Time		Sonar	
06	▷	"Noise Level Brg 004°; Evaluate as Mechanical; Designate as Contact S-4"	Contact bearing 004° true is evaluated as mechanical noise as determined by aural and visual classification procedures. Classification operator evaluates spectral frequency characteristics presented on classification recorder. Designated as contact S-4.
07	○	Tracking Party Mans Stations; One Sub-System is directed Continuously at S-4; another makes full sweeps	Tracking party mans stations. Passive track operator initiates track of contact S-4 using selection controls and track ball and observes main passive track CRT display. Initial detection operator continues search with visual and aural displays.
10	▷	"Contact Brg 001°, 3 DB louder, Slow Speed Screw, Light Cavitation; Probable Merchantman"	Passive track operator reports contact S-4 now bears 001° true and noise level has increased 3 db as observed by signal level meter. Through earphones, operator evaluates noise as slow speed screws causing light cavitation and estimates it as probable merchantman.
12	▷	"Negative"	In response to command's inquiry if sonar can get a turn count, sonar passive track reports that turn count cannot be determined.
14	▷	"Noise Level Brg 095° evaluated as Biological"	Sonar initial detection reports a noise level heard over earphones. Its bearing (095° true) is displayed on initial detection CRT. Operator evaluates it as biological, on basis of audible signal characteristics.
17	▷	"S-4 Brg 000°"	Sonar passive track reports contact S-4 now bears 000° true. Passive track operator follows signal by manually training compensator by means of track ball rotation.

Time		Sonar	
19	▷	"S-4 Brg 357°, D/E Angle +15°, Moderate Cavitation"	Sonar passive track reports contact S-4 now bearing 357°; D/E angle is (up) + 15° and producing moderate cavitation. Bearings and D/E angle are obtained from digital readout. Cavitation is determined aurally.
21	▷	"S-4 Brg 358°, Turn Count 62, Single Screw; estimate speed 8 kts; classify as Merchantman"	Sonar passive track reports contact S-4 now bearing 358°. Sonarman has established with earphones that turn count is 62 rpm and contact is a single screw ship. Speed is estimated at 8 knots. Using classification equipment, sonar supervisor has confirmed turn count and has classified contact as merchantman.
25	▷	"S-4 Brg 355°"	Sonar passive track reports contact S-4 now bears 355°.
27	▷	"S-4 Brg 354°, Moderate Cavitation"	Sonar passive track reports contact S-4 now bearing 354° and cavitating moderately. Same displays are monitored.
29	▷	"S-4 Brg 353°"	Sonar passive track reports contact S-4 now bears 353°.
31	▷	"S-4 Brg 354°, Closing"	Sonar passive track reports contact S-4 bearing 354° and closing range.
33	▷	"S-4 Brg 353°, Turn Count 64, Cavitating"	Sonar passive track reports contact S-4 bearing 353°, cavitating; turn count is now 64 rpm.
36	▷	"S-4 Brg 352°"	After change of depth, sonar passive track reports contact S-4 bearing 352°.
39	☐	Commences searching baffles	After changing course to clear the baffles, sonar initial detection closely observes sector that was previously restricted by baffles. CRT is monitored by initial detection operator and displays at frequency monitoring station are also observed.

Time		Sonar	
40	▷	"No additional contacts"	Sonar initial detection reports no additional contacts.
43	▷	"S-4 Brg 353°"	After change in depth, sonar passive track again reports contact S-4 bearing 353°.
44	▷	"No additional contacts; S-4 Brg 353°"	After periscope observation, sonar initial detection reports no additional contacts and passive track reports contact S-4 bearing 353°.
50	▷	"No additional contacts; S-4 Brg 350°"	After change in depth, initial detection reports no additional contacts and passive track reports contact S-4 bearing 350°.
54	○	Tracking party secures	Tracking party secures. Passive track operator secures tracking contact S-4. Initial detection operator continues watch and searches for additional contacts.
271	▷	"No contacts"	After course change to clear the baffles, sonar initial detection reports no contacts.
273	▷	"No contacts"	After course change in opposite direction, sonar initial detection reports no contacts.
288	○	Listens for Sonobuoys	After order from Command to listen for sonobuoys, initial detection operator and sonar supervisor monitor audio frequencies which are used by active sonobuoys and also monitor sonar intercept displays carefully.
290	▷	"No contacts"	Sonar initial detection reports no contacts.
392	▷	"No contacts"	After changing course to clear the baffles, sonar initial detection reports no contacts.
418	▷	"Power failure in sonar -all passive systems out of commission"	Sonar initial detection reports power failure in sonar and all passive systems are out of commission.

Time		Sonar	
424	▷	"Sonar back on the line and searching"	After full power restored, sonar initial detection reports sonar back on the line and searching.
425	▷	"Noise level brg 325°; spoking on passive sonar; machinery noise, possible submarine, light cavitation, high bearing drift"	Sonar initial detection reports a noise on earphones bearing 325°. Bearing lines appear on passive initial detection display. He evaluates noise as machinery noise, possible submarine, with light cavitation and a high bearing drift.
	▷	"Contact bearing 328°, identified as submarine; bearing drifting right, designate S-7; good bearing"	Sonar initial detection reports that new contact now bears 328°. Designates contact as S-7 and reports it is a good bearing. Classifies contact as submarine through sound received over earphones.
	▷	"Estimate range less than two miles"	As a result of noise level and high bearing rate, sonar initial detection estimates range at less than two miles.
426	▷	"Contact S-7 brg 334°, still cavitating, making 75 turns, estimate speed 9 kts; target is above us"	Sonar initial detection reports contact S-7 bearing 334°, still cavitating and above own ship. Turn count is 75 rpm and target speed is estimated at 9 knots.
427	▷	Mans battle stations	Sonar party mans battle stations. Sonar initial detection tracks own ship's torpedoes fired at contact S-7 on main scope and reports their bearings as 000° and 007°.
	○	Sonar begins tracking torpedoes	
	▷	"Torpedoes brg 000° and 007°."	
428	▷	"Contact brg 354°, still cavitating, speed unchanged at 9 kts."	Sonar initial detection reports contact S-7 now bearing 354°, still cavitating with speed unchanged at 9 knots.
429	▷	"Lost contact on our torpedoes; last bearings: 010° and 018°."	Sonar initial detection reports that contact on torpedoes has been lost from scope; last bearings were 010° and 018°.

Time			Sonar
431	▷	"Contact S-7 brg 015°, range opening, still cavitating"	Sonar initial detection reports that contact S-7 now bears 015°; audio indicates that range is opening and still cavitating.
432	▷	"Explosion bearing 020°"	Sonar initial detection reports explosion at bearing 020°.
433	▷	"Hear breaking-up noise, brg 020°"	Sonar initial detection reports hearing breaking-up noises at bearing 020°.
434	□	Begins searching baffles	After change in course, sonar initial detection searches the baffles with audio circuit in manual operation and monitors main scope with special emphasis on bearing sector previously astern.
436	▷	"No contacts"	Sonar initial detection reports no contacts after searching baffles.
490	○	Searches all around	Prior to change of depth, sonar is ordered to search all around.
492	▷	"No contacts"	After aural search all around and observation of initial detection scope on both broad band and fixed band sweeps, sonar reports no contacts.
496	▷	"No contacts"	After change in depth, sonar reports no contacts.
497	○	Secures from battle stations	Sonar secures from battle stations and resumes normal watch with one operator at initial detection station and second man monitoring frequency recorders and classification recorder.

8.6.2.4 ASW Action

00	▷	"Possible noise level brg 035°"	Sonar initial detection reports a possible noise level bearing 035°. Detection was made on basis of indications on frequency analysis DEMON recorder.

Time			Sonar
02	▷	"Noise level brg 040°; weak and intermittent"	Sonar initial detection observes a weak and intermittent noise level bearing 040° on fixed band CRT sweep set for frequency band observed on frequency of initial detection.
03	▷	"Lost contact on noise level; last brg, 034°"	Sonar initial detection reports that contact has been lost on noise level. Last bearing 034°.
09	▷	"Have regained contact; brg 033°, intermittent; tracking manually"	Sonar initial detection regains contact on bearing 033°. Noise is intermittent. Initial detection operator is tracking manually with audio frequency set at that of previous initial detection. Operator uses bearing finger wheel to control audio bearing and observes audio cursor on main scope to obtain bearing.
10	▷	"Contact brg 033°; noise level increasing. Machinery noise; designate S-9"	Sonar initial detection reports contact designated S-9 bearing 033°. Noise level as indicated on signal level meter is increasing and aural signal indicates it is machinery noise.
12	○	Tracking party mans stations; one sub-system is directed continuously at S-9; another continues making full sweep.	Tracking party mans stations. Sonar passive track initiates tracking of contact S-9. Other sonar personnel continue to monitor main scope, earphones, bearing-time recorder, frequency monitoring recorders, and classification recorder.
13	▷	"Estimate range of S-9 over 10 miles; brg 032°"	On basis of audio signal strength, sonar passive track estimates range of contact S-9 at over 10 miles. Bearing is now 032°. Bearing marks are transmitted to Fire Control manually.
17	▷	"S-9 brg 031°; definite engine noise"	Sonar passive tracking reports hearing definite engine noise on contact S-9 bearing 031°. Main CRT and earphones provide information.

Time			Sonar
21	▷	"Faint noise level brg 218°"	Sonar initial detection observes faint noise level on bearing-time recorder at approximate bearing 218°.
22	▷	"S-9 brg 029°; slow speed screws"	Sonar passive track reports contact S-9 at bearing 029° and hears slow speed screws.
23	▷	"Noise level brg 218° evaluated as fish"	Sonar initial detection, after listening to a selected audio frequency band, evaluates noise at 218° as fish.
25	▷	"S-9 brg 027°, light cavitation"	Sonar passive track reports contact S-9 bearing 027° and producing light cavitation. No major changes in equipment use are involved in the process. Occasional adjustments of CRT scale illumination, focus, and gain are made.
27	▷	"S-9 brg 025°"	Sonar passive track operator (continuing to train compensator) reports contact S-9 now bears 025°.
28	▷	"S-9 brg 026°"	Contact S-9 now bears 026°.
29	□	Checks bearing transmitter circuit; discovers blown fuse; replaces	Fire Control requests sonar check bearing transmitter circuit due to failure of Fire Control to receive sonar bearing. Sonar discovers blown fuse and replaces it.
30	▷	"Failure in bearing transmitter has been isolated and corrected"	Sonar reports to Fire Control that failure in bearing transmitter has been isolated and corrected. Receives command to man battle stations. Mans battle stations. No basic change required since tracking party already manning stations.
	○	Mans battle stations	
	▷	"S-9 brg 046°"	Sonar passive track reports contact S-9 now bears 046°.
31	▷	"S-9 brg 025°; light, single screw; turn count 65, estimate speed 9 kts, light cavitation; probable submarine"	Sonar passive track reports contact S-9 bearing 025°. Audio and frequency monitoring recorder indicates contact is single screw with 5 blades, turn count 65, light cavitation; probable submarine. Estimates speed at 9 knots.

Time			Sonar
35	▷	"Target brg 025°"	Sonar passive track reports that target bearing is remaining at 025°.
38	▷	"Target brg 024°, still cavitating slightly"	Sonar passive track reports change in S-9 bearing to 024°. Aural input indicates that target is still cavitating slightly. Slight cavitation is reported.
42	▷	"Target bearings are steady on 024°; no discernible drift; noise level increasing; target appears to be above us"	Sonar passive track continues to report that target S-9's bearings are steady on 024°. No discernible drift is observed. Operator reports that signal level meter indicates an increase in the noise level. Sonarman states that signal is coming from target apparently above ship.
46	▷	"S-9 brg 024°"	Sonar passive track again reports S-9's bearing 024°. Target is being tracked on main CRT.
51	▷	"Target is increasing speed; brg 025°"	Sonar passive track updates report on S-9 bearing, now 025°. He evaluates signals received on earphones and frequency monitoring recorder and estimates that the target's speed is increasing. Operator initiates ATF on target S-9.
52	▷	"Target brg 023°; turn count 102; heavy cavitation; estimate speed 13 kts"	Sonar passive track again reports bearing 023°. Change is observed on main CRT. Listening on the best frequency which he has "shaped" on the basis of information from the frequency monitoring station and the classification station, he makes a turn count and reports "turn count 102". He also reports heavy cavitation and a speed estimate of 13 knots.
53	▷	"Target is drawing left, now bears 021°; DE angle +10°"	Sonar passive track reports that target bearing is drawing left and new bearing is 021°. The depression/elevation angle is (up) +10°.
56	▷	"Target brg 018°, heavy cavitation; speed unchanged"	Sonar passive track reports target now bearing 018° and still producing heavy cavitation with speed unchanged.

Time		Sonar	
59	○	Obtains range to target with single ping	Sonar active track operator transmits single ping at target S-9 and stores range increment for computer to analyze for range and range rate.
	▷	"Range to target, 5800 yds., brg 015°"	Sonar active track obtains range and bearing readout on target and reports range 5800 yards and bearing 015°. Range and bearing are read out digitally above main active track display.
61	○	Begins tracking torpedoes	After firing torpedoes, both sonar tracking operators begin tracking torpedoes passively.
62	▷	"Torpedoes Running at 355° and 346°; target brg 011°"	Sonar tracking operators (both using passive mode) report torpedoes at 355° and 346°. Target being tracked passively in ATF is now bearing 011°.
63	▷	"Torpedoes running at 356° and 347°, very faint; target brg 007°, still cavitating"	Sonar track operators report torpedoes now bearing 356° and 347° and very faint as indicated on earphones. Target now bears 007° and still cavitating.
64	▷	"Lost contact on torpedoes; last brgs 357° and 348°; target now bears 004°"	Sonar track operators report lost contact on torpedoes at bearings 357° and 348°. Target S-9 now bears 004°.
65	▷	"Target has decreased speed; no longer cavitating; turn count 48 rpm; estimate speed 5 kts."	Sonar passive track operator reports target stopped cavitating and has decreased speed. Target S-9 out of ATF. Manual tracking is initiated. From frequency monitoring displays, turn count is reported as 48 rpm and speed is estimated at 5 knots.
67	▷	"Target is increasing speed again; heavy cavitation; brg 002°"	Sonar passive track, using earphones, hears heavy cavitation and indications of target's increasing speed. Target returned to ATF mode. Reports data and new bearing of 002°.
68	▷	"Single explosion on last target bearing"	Sonar reports single explosion heard on last target bearing.

Time			Sonar
69	▷	"Breaking up noises brg 001°"	Sonar reports hearing breaking up noises on bearing 001°.
70	□	Searches all around	In response to orders from command, sonar initial detection and track operators conduct full 360° passive search with both preformed beam (conformal) and spherical systems.
72	▷	"Complete sweep all around; no contacts"	Sonar supervisor reports no contacts after complete sweep all around.
74	○	Secures from battle-stations	Sonar secures from battlestations and resumes normal watch on initial detection station. Observes frequency monitoring recorders, bearing-time recorder and classification recorder.

8.6.3 Fire Control Operations Sequence Test of Console Feasibility

As a preliminary criterion of the ability of the designed console to fulfill the fire control mission the displays and controls have been tested against an actual operation sequence for a THRESHER class submarine. That is, the following charts demonstrate where and how aspects of the fire control mission would be handled on the proposed console.

Only the "On-Station Patrol" and "ASW Action" phases have been submitted to test since the other phases have minimal fire control entries and these are repeated in the phases covered.

8.6.3.1 On-Station Patrol

Time		Fire Control	Remarks
1	□	Places F/C Console in operation; selects appropriate sensor as input	Weapons console is turned on at monitoring console. Contact is assigned to analyzer "A" via analyzed keyboard. Passive sonar sensor is selected by the operator of analyzer "A"
7	○	Tracking party mans stations; selects method of target analysis; checks latitude proofing and firing displays; determines speed correction, if necessary, and inserts into ballistic plugs; checks tube ballistic switches; continuously monitors bearing inputs from sensors; also monitors own-ship inputs for course, speed, depth; commences target motion analysis	The console is manned by two operators; the tactical display operator and one target analyzer operator. The tactical display operator monitors own ship's course, speed, and depth in the readouts on the center panel. The analyzer operator monitors bearing information in the "A" target localization display. Computer commences analysis after performing other functions mentioned (See section concerning "Special Considerations")
15	▷	"Request course 270° to aid fire control solution"	Tactical display operator requests course to maximize bearing rate (B).
19	○	Enters D/E angle; attempts analysis of target depth	Entered automatically from surveillance console.
[illegible]	○	Enters target speed estimate into motion analysis	Target analyzer operator enters absolute speed estimate and associated error estimate via keyboard. (See section on analyzer keyboard) Entry appears [illegible] localization display.

Time		Fire Control	Remarks
22	▷	"Initial solution for S-4: course 265°, speed kts, range 16000 yds; D/E angle confirms that target is on surface"	Solution appears on target localizat on display
23	○	Obtains solution	Same as 22
25	▷	"Course to intercept: 322°, speed 10 kts; time of intercept 1842"	Reads solution.
26	○	Monitors new own ship inputs	Tactical display operator continues to monitor own-ship course, speed, and depth.
29	○	Continues to update solution	Computer continues to update solution on the basis of sonar bearings.
34	▷	"Estimate contact range, 6000 yds; present solution: course 251°, speed 9 kts"	Analyzer operator reads solution from target localization
43	□	Selects periscope as sensor input	Analyzer "A" operator selects periscope as sensor via keyboard.
43^1	□	Monitors periscope bearing input	Operator monitors bearing on localization display of analyzer "A"
47	□	Monitors bearing and range inputs from periscope; compares these with generated values; makes adjustments as necessary	Monitors bearing and range from periscope on analyzer "A" and compares these with sonar bearing on analyzer "A".
48	○	Compares estimated angle-on-the-bow with generated AOB	Compares target course derived from angle-on-the-bow with course generated by computer on the basis of sonar data.
54	○	Tracking party clears console of S-4 inputs and secures	Analyzer operator clears analyzer "A" by pressing clearing button of the analyzer

Time		Fire Control	Remarks
418-424	▷	Power failure	All functions mentioned are handled by monitoring console operator
425	○	Orders tubes #1 and #4 made ready in all respects	Tubes #1 and #4 are prepared for firing by pressing the tube numbers and the weapon preparation order button. The tactical display operator proceeds through the preparation sequence until both weapons are ready to fire. When tubes #1 and #4 are fully prepared, the "Ready" indicator will be lighted in the two tube preparation columns.
425^{1}	□	Inserts pre-set functions for snapshot situation	Computer selects and inserts functions.
425^{2}	○	Inserts deflection angles, running depth, and enabling run	Computer selects deflection angles and enabling run. Analyzer operator inserts depth estimate.
426	○	"Tubes #1 and #4 ready in all respects"	Reports weapons ready.
426^{1}	○	Places tubes #1 and #4 standby switches in standby	Weapons are in standby when "ready" indicator is lighted.
426.5	○	Depresses firing key for tube #1	Tactical display operator presses firing button
426.5^{1}	▷	"Tube #1 fired electrically"	Reports firing response as shown on status panel.
426.5^{2}	□	Notes time of firing	Firing time indicator on weapon status panel shows firing time.
427	○	Depresses firing key for tube #4	Computer fires second weapon.
427^{1}	▷	"Tube #4 fired electrically"	Reports firing response.
427^{2}	□	Notes time of firing	See Time 426.5
427^{3}	□	Mans battle stations	Third operator to man analyzers "C" and "D" is stationed.

Time		Fire Control	Remarks
428	○	Inserts speed and range estimates	Inserts estimates of range and speed into analyzer "A".
428[1]	○	Inserts data into analyzer	Data inserted automatically.
428[2]	▷	"Target range estimated 3500 yds, speed 9 kts, course 100°"	Analyzer "A" operator reads range, course, and speed from localization display.
429	○	Orders tubes #1 and #4 reloaded with Mk 37 Mod 0 torpedoes	Tactical display operator assigns Mk 37 Mod 0 torpedoes to tubes #1 and #4 via the keyboard.
429[1]	○	Orders tubes #2 and #3 made ready in all respects	Tactical display operator proceeds through weapon preparation sequence. (See time 425) Reports ready.
430	○	Inserts pre-set and synchronous functions	These functions are selected and inserted by the computer.
431	▷	"Tubes #2 and #3 ready in all respects"	Tactical display operator reports that tubes #2 and #3 are ready.
437	○	Inserts pre-set functions for snapshot into both tubes	Computer selects and inserts these functions.
437[1]	▷	"Tubes #1 and #4 have been placed in ready condition"	
497	○	Secure all tubes	Instructs torpedo men to secure all tubes.

8.6.3.2 ASW Action

1	□	Places F/C console in operation: selects appropriate sensor as input	Weapons console is turned on at monitoring console. Contact is assigned to analyzer "A". Sonar sensor selected at analyzer keyboard. Two men are seated at the console.
2	○	Monitors own ship and target inputs	Target inputs are monitored on target data display. Own ship C, S, & D are monitored at readouts to the right of the tactical display.

Time		Fire Control	Remarks
12	○	Tracking party mans stations: selects method of target analysis; checks latitude proofing and firing displays; determines speed correction, if necessary, and inserts into ballistic plug.	Analyzer operator monitors B & $\dot{B}$. Other functions are handled by the computer (See "Special Considerations" section)
12^1	□	Checks tube-ballistic switches; continuously monitors bearing inputs from sensors and own ship inputs for course, speed, and depth	Continues to monitor target bearing information and own ship inputs (See Time 3)
13	□	Commences analysis of target bearing drift	Monitoring of B & $\dot{B}$ continues.
19	▷	"S-9 BRG drift 1-1/2 DG left"	Reports $\dot{B}$ in degrees per minute.
21	○	Continuous analysis of bearing drift	Continues $\dot{B}$ input analysis.
21^1	□	Selects appropriate sensor for new motion analysis	New contact assigned to analyzer "B" via keyboard.
23	○	Clears analyzer of inputs	Analyzer "B" is cleared of contact via keyboard.
24	▷	"Request course change to obtain range estimate"	Course change is requested to maximize $\dot{B}$ in order to obtain range.
25	□	Obtains preliminary estimate of target range; inserts range into analyzer; assumes target speed of 10 kts and inserts speed into analyzer; obtains initial solution	Preliminary range estimate is calculated by the computer on the basis of ΔB obtained from own ship zig. This speed estimater is automatically inserted.
26	▷	"Initial solution: course 240 , speed 10 kts, range 16,000 yds"	The initial solution is displayed on the localization display of analyzer "A".
28	□	Notes failure of analyzer to receive sonar bearing; inserts bearing manually	Bearing transmitter failure would be noted by monitoring console operator.

Time		Fire Control	Remarks
28½	▷	"Sonar, check your 'bearing transmitter' circuit; last bearing was not received by analyzer"	Monitoring console operator would notify sonar of this malfunction.
30	○	Mans battle stations	An additional operator now takes over operation of analyzers "C" and "D".
30½	○	Evaluates eccentric BRG, drops from computer analyzer	Eccentric bearing is rejected by the computer.
31	○	Inserts new estimates of target speed; obtains revised solution (inserts estimate of target length)	Analyzer operator inserts speed estimate and error estimate via analyzer. (See section on analyzer keyboard) Revised solution appears in localization display. Target length handled by sonar.
32	▷	"Present Target solution: course 235°, speed 9 kts, range 15,500 yds"	Reports solution from localization display
34	○	Sets mode-of-operation selector switch to pre-set mode; sets in firing order	Analyzer operator assigns target "A" to tubes #1 and #4. Center operator assigns Mk 37-0 torpedoes to tubes #1 and #4. Computer sets firing order.
37	○	Orders tubes made ready with exception of opening the outer doors	Center operator orders "weapon ready" and "flood tube" for tubes #1 and #4 by pressing tube numbers and weapon preparation button.
38	○	Continues to update solution	Continues monitoring solution and kill probability.
39	▷	"Present target solution: course 229°, speed 9 kts, range 10,500 yds"	Reads current solution from the localization display.
41	○	Inserts ordered non-synchronous functions	Non-synchronous functions are selected and inserted by the computer.
42	▷	"Present solution: course 233°, speed 9 kts, range 8200 yds; evaluate solution as good"	Reads solution from display. Evaluation would be based on kill probability display.

Time		Fire Control	Remarks
45	○	Inserts ordered enabling runs and running depths	Enabling runs and running depths are selected and inserted by the computer.
48	○	Orders outer doors open on #1 and #4	Opens outer doors by proceeding to the next step in the preparation sequence. Arms weapons.
50	▷	"Tubes #1 and #4 ready in all respects"	Reports that weapons are ready. This is indicated by a light appearing behind the "ready" readout in the tube preparation column.
52	○	Inserts new target speed; obtains new solution	Speed estimate inserted with error estimate via analyzer keyboard. New solution appears.
53	○	Estimates target depth	Inserts depth estimate via analyzer keyboard.
54	▷	"Target course steady on 227°; estimate target depth at 250 ft, target range at 6100 yds"	Solution from localization display.
57	○	Inserts change in torpedo speed settings	Torpedo speed is set by the computer.
58	○	Orders torpedomen to stand by tubes #1 and #4.	
59		Inserts range; obtains final check on solution	Selects active range sensor. Range automatically goes to computer.
59^1		"Correct solution"	
60	○	Depresses firing key: starts timer	Pressing firing button starts mean intercept timer running.
60^1	▷	"Fire #1 -- Tube #1 fired electrically"	Reports tube #1 fired
60^2	○	Depresses firing key: starts timer	Tube #4 is fired by the computer
60^3	▷	"Fire #4 -- Tube #4 fired electrically	Reports Tube #4 fired.

Time	Fire Control	Remarks
63 ▷	"Contact steady on course 227°; estimate depth 270 ft, range 5700 yds"	Reads solution from display
65 ○	Inserts new data	Inserts speed estimate.
66 ▷	"Weapons should be within acquisition range"	This is determined from mean time to intercept readout on alpha-numeric display.
69 ▷	"Time analysis indicates first torpedo hit target"	See Time 66.
74 ○	Orders all tubes secured; secures from battle stations	Orders torpedomen to secure all tubes.

8.6.4 Command Operations Sequence Test of the Console Feasibility

The command station has been designed to facilitate the command functions of information processing and decision making. As such, the evaluation of the station consists entirely of stipulating how its input (information) is presented to the Commanding Officer; the station output (commands) consists of verbal communication from command to the appropriate station. In the analysis, then, the emphasis is upon indicating the display or means by which the Commanding Officer or the O.O.D. is presented with information transmitted. In the case of commands issued, the addressee only is indicated, since all commands are verbal.

One portion of the operational sequence ("Getting Underway") has been omitted, since the activities during this period are conducted while the Commanding Officer is on the bridge and not at the command station. It is likely that this station will be unmanned at this time.

8.6.4.1 Transit

LEGEND

INFORMATION TRANSMITTED ▷

INFORMATION ADDRESSEE ○

SELF-INITIATED ACTION □

Time	Command		Information Display, Control Commands
0	□	Sounds diving alarm	All stations
	○	"Straight board" (Ship Control)	Verbal report
	○	"Planes working satis-factorily" (Ship Control)	Verbal report
	▷	"110 ft"	Ship control
	○	"All vents shut" (Ship Control)	Verbal report
	○	"All compartments on the line" (Operations)	Verbal report
2	□	Monitors pertinent aspects of ship control	Verbal report
	○	"No contacts" (Sonar)	Verbal report
3	▷	"All ahead 1/3"	Ship control
4	▷	"Get a satisfactory trim"	Ship control
	○	"Permission to cycle the vents" (Ship Control)	Verbal request
5	▷	"Permission granted"	Ship control
12	○	"Steady on 110 ft; trim satisfactory" (Ship Control)	Verbal report (SQUIRE can be monitored from command station)
13	▷	"Secure the phones"	Operations
14	▷	"All ahead full; 200 ft-10° down angle"	Ship control

Time	Command		Information Display, Control Commands
16	O	"Steady on 200 ft 10° down angle (Ship Control)	Verbal report, SQUIRE
20	O	"Biological noise bearing 164°"(Sonar)	Verbal report, SQUIRE
31	O	"Gyro failure" (Ship Control)	Verbal report
31	▷	"Shift repeater input from master to auxiliary"	Ship control
31	▷	"Shift to manual control; steer magnetic heading"	Ship control
34	O	"Auxiliary gyro now on the line" (Operations)	Verbal report
35	▷	"Shift to automatic control when system has stabilized"	Ship control
36	O	"Repeater back on line; have shifted to automatic control" (Ship Control)	Verbal report
1600	▷	"All ahead 1/3"	Ship control
1601	▷	"Make preparations to dump garbage through the GDU"	Operations
1602	▷	"100 ft"	Ship control
1604	▷	"Right 10° rudder; steady up on 270°"	Ship control
1605	▷	"Search the baffle"	Sonar
	O	"Steady on 270°" (Ship Control)	Verbal report, SQUIRE
1608	O	"No contacts" (Sonar)	Tactical display
1609	▷	"Right 10° rudder; steady up on 090°"	Ship control

Time		Command	Information Display, Control Commands
1610	▷	"Prepare to ventilate"	Ship control
1620	▷	"Standby for radio and ECM reception"	Operations
1621	▷	"70 ft"	Ship control
1622	○	"Steady on 70 ft" (Ship Control)	Verbal report, SQUIRE
	▷	"Look around"	Operations
1623	□	Raises periscope, makes 360° search	Operations; C.O. may monitor TV periscope
1625	▷	"64 ft"	Ship control
1626	□	Continues visual search with periscope	Operations
1627	▷	"62 ft"	Ship control
1628	▷	"Raise whip and ECM masts; search all bands"	Operations
1630	○	"Rigged to ventilate; trim satisfactory" (Ship Control)	Verbal report
1631	▷	"Commence ventilating"	Ship control
1635	▷	"Load the GDU"	Operations
1640	▷	"Pump bilges; blow down the boilers"	Ship control
1645	○	"No ECM contacts" (Operations)	Verbal report
1651	○	"Possible noise level brg 320°" (Sonar)	Verbal report
	○	"Engineering reports secured from blowing boilers" (Operations)	Verbal report
1654	○	"Contact brg 320° evaluated as fish" (Sonar)	Verbal report

Time	Command	Information Display, Control Commands
1654 (Cont)	○ "Fleet broadcast secured; antenna lowered" (Operations)	Verbal report
1660	○ "Secured the GDU"	Verbal report
1668	○ "Engineering reports all bilges dry; secured pumping"	Verbal report
1670	○ "All scheduled operations completed" (Operations)	Verbal report
1685	▷ "Secure ventilating"	Ship control
1694	○ "Secured from ventilating" (Ship Control)	Verbal report
1695	□ Lowers periscope	Operations
1696	▷ "200 ft"	Ship control

8.6.4.2 On Station Patrol

Time	Command	Information Display, Control Commands
0	○ "Faint noise level, brg 010°" (Sonar)	Contact data appears as a bearing line on Tactical Display; data on signal strength communicated verbally by sonar. Bearing Rate and other target data appears on the Tactical Display as it becomes known
2	○ "Noise level brg 009° weak and intermittent" (Sonar)	" "
4	○ "Noise level brg 005°" (Sonar)	" "
5	▷ "Left 15° rudder; steady on 000°"	Ship control
6	○ "Noise level brg 004°; evaluate as mechanical; designate as contact S-4" (Sonar)	Noise level data communicated verbally; all else appears automatically on tactical display
7	▷ "Station the tracking party"	Fire control/surveillance

Time		Command	Information Display, Control Commands
9	▷	"Make turns for 3 kts"	Ship control
10	○	"Contact brg 001°, 3DB louder, slow speed screw, light cavitation, probable merchantman" (Sonar)	Bearing data automatically displayed on tactical display Classification automatically displayed on the alpha-numeric display. Signal level communicated by voice
	○	"XXX freighter has been reported in this area" (Operations)	Verbal report
12	▷	"Sonar, can you get a turn count?"	Verbal request to sonar
	○	"Negative" (Sonar)	Verbal report
14	○	"Noise level brg 095° evaluated as biological" (Sonar)	Verbal report (bearing lines on Tactical Display appear only when target is given a designation by sonar)
15	○	"Request course 270° to aid FCS" (Fire Control)	Verbal communication
16	▷	"Left 15° rudder; steady on 270°"	Ship control, after evaluation of relevant tactical parameters affecting course change
17	○	"S-4 brg 000°" (Sonar)	Automatic presentation on tactical display
19	○	"S-4 brg 3[illegible]°, D/E angle 15°, moderate cavitation" (Sonar)	Bearing data appears automatically on tactical display, other data communicated verbally
21	○	"S-4 brg 358°, turn count 62, single screw; estimate speed 8 kts, classify as merchantman (Sonar)	Bearing and speed appear automatically on tactical display other data communicated verbally save screw count, since target speed estimate [illegible]pears on tactical display; classi[illegible]ation appears on the alpha-numeric [illegible]play.
[illegible]	○	[illegible] reports [illegible]	[illegible] deemed necessary in current [illegible]me; data appear on tactical dis[illegible], FCS reflected in kill proba[illegible]y values; Fire Control should [illegible] however, on the "goodness" [illegible]

Time		Command	Information Display, Control Commands	:rol Commands
23	▷	"Give me a course to intercept target, using 10 kts"	Operations	
25	O	Fire Control reports intercept course	Operations will report in the current schemes.	the cur-
25	O	"S-4 brg 355°" (Sonar)	Appears automatically on tactical display	tactical
26	▷	"Right 10° rudder; steady on 322°"	Ship control based on intercept course solution	:ercept
	▷	"All ahead 2/3; make turns for 10 kts"	" "	
27	O	"S-4 brg 354°, moderate cavitation" (Sonar)	Bearing data appears on tactical display automatically, cavitation reported verbally, if at all	actical vitation all
28	▷	"Advise me when contact range is 6000 yds"	Readily seen on tactical display	display
29	O	"S-4 brg 353°" (Sonar)	Tactical display	
31	O	"S-4 brg 354° closing" (Sonar)	Tactical display	
33	O	"S-4 brg 353°, turn count 64, cavitating" (Sonar)	Tactical display shows bearing, turn count is unnecessary since speed estimate is displayed	aring; since ed
34	O	Fire Control reports solution	Not necessary in current scheme	scheme
35	▷	"All ahead 1/3"	Ship control	
36	▷	"100 ft"	Ship control	
36	O	"S-4 brg 352°" (Sonar)	Tactical display	
37	▷	"Right 20° rudder; steady on 000°"	Ship control	
	▷	"Sonar, swinging ship; search the baffles"	Ship control	
39	▷	"Left full rudder; steady on 2[illegible]°"	Ship control	

Time		Command	Information Display; Control Commands
40	○	"No additional contacts" (Sonar)	Tactical display
41	▷	"70 ft"	Ship control
43	▷	"Look around"	Operations
	○	"S-4 brg 353°" (Sonar)	Tactical display
	□	Raises periscope; makes 360° search; trains on target, presses bearing-mark switch, lowers periscope	Operations; may monitor TV display
	▷	"No other contacts; target is a merchant freighter; angle on the bow port 65°"	" "
44	○	"No additional contacts; S-4 brg 353°" (Sonar)	Tactical display
46	▷	"68 ft"	Ship control
47	▷	"Observation"	Operations; may monitor TV periscope.
	□	Raises periscope trains on target; depresses bearing-mark switch; adjusts stadimeter; depresses range-mark switch; notes nationality of vessel; lowers periscope	" "
48	▷	"Target is a XXX freighter; angle-on bow port 70°"	" "
49	▷	"200 ft"	Ship control
50	○	"No additional contacts; S-4 brg 350°" (Sonar)	Tactical display

Time	Command		Information Display, Control Commands
51	▷	"Secure the approach; navigator, give me a course to original track"	Operations
53	○	"Recommend 072°" (Operations)	Verbal report
54	▷	"Right 20° rudder; steady on 072°"	Ship control
	▷	"Secure the tracking party"	Fire Control/surveillance
= = =	= = =	= = = = = = = = = = = =	= = = = = = = = = = = =
267	○	"Next schedule fleet broadcast: 15' recommend navigational fix" (Operations)	Verbal reports
	○	"Engineering requests blow down boilers" (Operations)	Verbal reports
	▷	"Standby the radio, Loran and ECM; ECM, search all bands"	Operations
267	▷	"Make ready to blow down boilers, dump garbage, and pump bilges"	Operations
268	▷	"Make your depth 100 ft"	Ship control
271	▷	"Sonar, swinging ship; search the baffles"	Sonar
	▷	"Left 15° rudder; steady on 040°"	Ship control
	○	"No contacts" (Sonar)	Verbal report
273	▷	"Right 20° rudder; steady on 110°"	Ship control
	○	"No contacts"	Verbal report
275	▷	"Left [illegible] rudder; steady on 06[illegible]"	Ship control

Time	Command		Information Display, Control Commands
277	▷	"70 ft"	Ship control
279	▷	"Look around"	Operations
279	□	Raises periscope, makes 360° search	Operations
280	▷	"64 ft"	Ship control
282	▷	"Raise the masts"	Operations
284	○	"ECM contact brg 050° A/C radar, faint signal" (Operations)	Verbal report
	▷	"Down all masts; 700 ft; 25° down bubble; all ahead full"	Ship control, Operations
287	▷	"Steady on 70 ft" (Ship Control)	Verbal report: SQUIRE visible to C.O.
288	▷	"All ahead 1/3; sonar, listen for sonobuoys"	Ship control, Sonar
290	○	"No contacts" (Sonar)	Verbal report
384	○	"Next fleet broadcast scheduled for 0800" (Operations)	Verbal report
	▷	"Standby the ECM, Loran, and radio; ECM, search all bands"	Operations
	▷	"Make all preparations to pump bilges, dump garbage, and blow down boilers"	Operations
385	▷	"100 ft"	Ship control
391	▷	"Sonar, swinging ship; search the baffles"	Sonar
392	▷	"Left full rudder; steady on 085°"	Ship control
396	○	"No contacts" (Sonar)	Tactical display

Time	Command		Information Display, Control Commands
397	▷	"Make your depth 70 ft"	Ship control
399	□	"Look around"	Fire control
399	□	Raises periscope and makes full search	Operations
400	▷	"63 ft"	Ship control
402	▷	"Raise the masts"	Operations
404	○	"No ECM contacts" (Operations)	Verbal report
405	▷	"Commence pumping bilges; commence eject-ing garbage"	Operations
407	▷	"Permission granted to blow down boilers"	Operations
408	○	"ZBO message indicators, no traffic this ship" (Operations)	Verbal report
412	○	"Boiler blowing com-plete" (Operations)	Verbal report
417	○	"GDU secured; bilges dry" (Operations)	Verbal report
418	○	"Lost automatic control" (Ship Control)	Verbal reports
	○	"Power failure: all passive systems out" (Sonar)	Verbal reports
	○	"Power loss to auto-matic course computer" (Fire Control)	Verbal reports
418	▷	"Shift to emergency steering and planes; make your depth 300 ft"	Ship control
	▷	"Lower all masts"	Operations
	□	"Lower periscope"	Operations

Time	Command		Information Display, Control Commands
418 (Cont)	O	"Engineering reports loss of power to operations distribution feeder panels" (Fire Control)	Verbal report
419	▷	"Have the engineer officer report as soon as the failure has been isolated"	Fire Control
422	O	"Engineering reports full power restored" (Fire Control)	Verbal report
423	▷	"Shift to primary mode"	Ship control
424	O	"Sonar on line and searching"	Verbal report
	O	"Fire Control on the line"	Verbal report
425	O	"Noise level brg 325°; spoking on passive sonar machinery noise, possible submarine, light cavitation, high bearing drift" (Sonar)	Bearing, and bearing drift appears on tactical display; other data communicated verbally
	▷	"Left full rudder; steady on 325°"	Ship control
	▷	"Snapshot, snapshot, make ready the ready tubes in all respects"	Fire Control
	O	"Contact bearing 328°, submarine, bearing drift 10° right per minute, designate S-7"	Tactical display
	O	"Estimate range less than two miles"	Tactical display
	▷	"Tube deflection angles of 5° and 15°; set running depth at 150 ft and 400 ft; set enabling runs at 1000 yds"	Weapon parameters are determined by the computer

Time	Command		Information Display, Control Commands
426	▷	"Right 10° rudder; steady on 345°"	Ship control
	○	"Contact S-7 brg 334°, cavitating making 75 turns, speed est. 9 kts; target above us" (Sonar)	Tactical Display (Turn count unnecessary, reflected in speed estimate)
	○	"Tubes #1 and #4 ready in all respects" (Fire Control)	Verbal report
426:5	▷	"Shoot"	The current proposal is for the C.O. to direct the opening of doors and warhead activation. After this, time to shoot is determined by the computer
	○	"Tube #1 fired electrically" (Fire Control)	Verbal report
427	▷	"Shoot"	Computer determined
	○	"Tube #4 fired electrically" (Fire Control)	Verbal report
	▷	"Man battle stations"	All stations
	▷	"Sonar, follow the torpedoes"	Sonar
	○	"Torpedoes brg 022° and 027°" (Sonar)	Verbal report
428	▷	"Get a fire control solution"	Fire Control
	○	"Contact brg 354° cavitating, speed unchanged at 9 kts" (Sonar)	Tactical display
	○	"Target range est. 3500 yds, 9 kts, course 100°" (Fire Control)	Tactical display

Time		Command	Information Display, Control Commands
429	▷	"Reload #1 and #4 with Mk 37 Mod 0 torpedoes"	Fire Control
	○	"Lost contact on torpedoes; last bearings 022° and 028°"	Verbal report
	▷	"Make ready tubes #2 and #3 in all respects"	Fire Control
430	▷	"We will shoot a depth spread; set #2 for 200 ft, #3 for 650 ft, enabling run 2000 yds, high speed, no limit, active homing, snake search"	Fire control
431	○	"S-7 brg 015°, range opening; still cavitating" (Sonar)	Tactical display
	○	"Tubes #2 and #3 ready in all respects" (Fire Control)	Verbal report
432	○	"Explosion bearing 020°"	Verbal report
433	○	"Hear breaking-up noise, brg 020°"	Verbal report
434	▷	"Sonar, coming right; search the baffles"	Sonar
	▷	"Right 15° rudder; steady on 100°"	Ship control
436	○	"No contacts" (Sonar)	Tactical display
437	▷	"Makes tubes #1 and #4 ready for snapshot"	Fire Control
	○	"Tubes #1 and #4 ready" (Fire Control)	Verbal report
490	▷	"Sonar, search all around"	Sonar
492	○	"No contacts" (Sonar)	Tactical display
493	▷	"Make your depth [illegible]00 ft"	Ship control

Time	Command		Information Display, Control Commands
496	○	"No contacts" (Sonar)	Tactical display
497	▷	"Secure all tubes"	Fire control
498	▷	"Secure from battle stations"	All stations

8.6.4.3 ASW Action

Time	Command		Information Display, Control Commands
0	○	"Possible noise level brg 035°" (Sonar)	Verbal report
1	▷	"Make turns for 3 kts"	Ship control
2	○	"Noise level brg 040° weak and intermittent" (Sonar)	Verbal report
3	▷	"Left 15° rudder; steady on 050°"	Ship control
	○	"Lost contact on noise level, last brg 034°" (Sonar)	Verbal report
4	▷	"Make your depth 400 ft; rig ship for quiet condition II"	Ship control
9	○	"Regained contact brg 033°, intermittent tracking manually" (Sonar)	Verbal report
10	▷	"350 ft"	Ship control
	○	"Contact brg 033°, noise level increasing, machinery noise, designate S-9" (Sonar)	Tactical display and verbal report
12	▷	"Come left to 030°, station the tracking party"	Ship control, sonar, fire control
	○	"Ship rigged for quiet condition II" (Operations)	Verbal report
13	▷	"Request range estimate"	Sonar, Fire Control

Time		Command	Information Display, Control Commands
13 (Cont)	○	"Estimate range over 10 miles, brg 032°" (Sonar)	Tactical display
	▷	"Left 15° rudder, steady on 005°"	Ship control
17	○	"S-9 brg 031°, definite engine noise" (Sonar)	Tactical display, verbal report
18	▷	"Left 20° rudder, steady on 310°"	Ship control
19	○	"S-9 brg drift 1-1/2° left" (Sonar)	Tactical display
21	▷	"Right 15° rudder, steady on 000°"	Ship control
	○	"Faint noise level brg 218°" (Sonar)	Verbal report
22	○	"S-9 brg 029°, slow speed screws" (Sonar)	Tactical display and verbal report
23	○	"Noise level brg 218° evaluated as fish" (Sonar)	Verbal report
24	○	"Request course change to obtain range estimate" (Fire Control)	Verbal request
	▷	"Left full rudder, steady on 315°"	Ship control, based on evaluation of tactical situation and FCS accuracy needs
25	○	"S-9 brg 027°, light cavitation" (Sonar)	Tactical display
26	○	Fire Control reports initial solution	Tactical display for data, solution reflected in kill probability on alpha-numeric display with verbal report on "goodness" of FCS
27	○	"S-9 brg 025°" (Sonar)	Tactical display
28	▷	"Right 15° rudder, steady on 330°, all ahead 2/3, build up turns slowly"	Ship control

Time		Command	Information Display, Control Commands
28 (Cont)	○	"S-9 brg 026°" (Sonar)	Tactical display
30	▷	"Man battle stations"	All stations
	○	"S-9 brg 026°" (Sonar)	Tactical display
31	○	"S-9 brg 025°, light, single screw, turn count 65, est. speed 9 kts, light cavitation, probable submarine" (Sonar)	Tactical display (Turn count not necessary)
32	○	Fire Control presents solution	Data on tactical display, FCS reflected in kill probability, verbal report on "goodness" of FCS
	▷	"Come right to 350°"	Ship control
33	○	"All stations on the line, battle stations have been manned throughout the ship" (Operations)	Verbal report
34	▷	"We will fire an initial salvo of two Mk 37-0s; firing order will be #1 #4"	Weapon and tube specification, guidance and ejection mode to fire control, firing order is computer determined
35	○	"Target brg 025°" (Sonar)	Tactical display
37	▷	"Make ready all tubes with the exception of opening the outer doors"	Fire control
38	○	"Target brg 024°, still cavitating slightly" (Sonar)	Tactical display
39	○	"Fire control reports FCS"	Data appear on tactical display, solution status reflected in kill probability, FCS "goodness" reported verbally
40	▷	"All ahead 1/3; steer 354°"	Ship control

Time		Command	Information Display, Control Commands
41	▷	"Use following nonsynchronous functions: passive homing, low speed, snake search, no limits"	Fire Control
42	○	"Target brg steady on 024°, no discernable drift; noise level increasing, target appears to be above us"	Tactical display
	○	Fire Control reports solution	Data appear on tactical display, solution status reflected in kill probability
45	▷	"Set enabling runs for 1,000 yds, set running depths at 10° and 25°"	Parameters set by computer in present scheme
46	○	"S-9 brg 024°" (Sonar)	Tactical display
48	▷	"Open the outer doors on #1 and #4"	Fire control
50	○	"Tubes #1 and #4 ready in all respects" (Fire Control)	Verbal report
51	○	"Target increasing speed; brg 025°" (Sonar)	Tactical display
52	○	"Target brg 023°; turn count 102 heavy cavitation est. speed 13 kts" (Sonar)	Tactical display
53	○	"Target drawing left, now bears 021°; D/E angle + 10° (Sonar)	Tactical display
54	○	"Target course steady on 227°; estimate depth at 250 ft, range at 6,000 yds" (Fire Control)	Tactical display
55	○	"Target brg 018°, heavy cavitation, speed unchanged" (Sonar)	Tactical display

Time		Command	Information Display, Control Commands
57	▷	"Change torpedo speed settings to high"	Computer does this automatically
58	▷	"Standby #1 and #4	Not necessary, since firing is automatic by computer after outer doors are open and warhead is activated
59	▷	"Get a single ping range"	Sonar
	○	"Range to target 5800 yds, brg 015°" (Sonar)	Tactical display (Verbal report may supplement)
	○	"Correct solution" (Fire Control)	Verbal report
60	▷	"Shoot"	Computer determined
	○	"Tube #1 fired electrically" (Fire Control)	Verbal report
	▷	"Shoot"	Computer controlled
	○	"Tube #4 fired electrically (Fire Control)	Verbal report
61	▷	"Sonar, follow the torpedoes"	Sonar
	▷	"Make turns for 2 kts; rig ship for quiet condition III"	Ship control, Operations
62	○	"Torpedoes running at 355°, 346°; target brg 011°" (Sonar)	Verbal report, tactical display
	▷	"Reload #1 and #4 with Mk 37-0s"	Fire Control
63	○	"Torpedoes running at 356° and 347°, very faint, target brg 007°, still cavitating" (Sonar)	Tactical display, verbal report
	○	"Contact steady on course 227°; estimate depth 270 ft, range 5700 yds" (Fire Control)	Tactical display

Time	Command		Information Display, Control Commands
64	O	"Lost contact on torpedoes; last brgs 357° and 348°; target now bears 004°" (Sonar)	Verbal report, tactical display
65	O	"Target has decreased speed; no longer cavitating; turn count 48 rpm; estimate speed 7 kts" (Sonar)	Tactical display
66	⊙	"Weapons should be within acquisition range" (Fire Control)	Verbal report
67	O	"Target increasing speed; heavy cavitation; brg 002°" (Sonar)	Tactical display
68	O	"Single explosion on last target brg" (Sonar)	Verbal report
69	O	"Time analyses indicates first torpedo hit target" (Fire Control)	Verbal report
70	▷	"Right full rudder; steady on 175°; sonar, search all around"	Ship control, sonar
72	O	"Complete sweep all around; no contacts" (Sonar)	Verbal report
74	▷	"Secure all tubes; secure from battle stations"	All stations

IX

DATA PROCESSING REQUIREMENTS

9.1 INTRODUCTION

The problem of defining the data processing requirements for the system described in the previous sections can be approached from two diametrically opposed points of view. From the first point of view the conventional equations solved by previous systems plus any additional processing necessary to drive the new displays would be taken as the basis for establishing the required computer characteristics. From the second point of view the computer characteristics would be established on the basis of those equations which would be most useful in improving the combat effectiveness of the submarine. This study has taken the second approach.

During phases I through V of ONR's SUBIC program a methodology has been established for arriving at the characteristics of an integrated "Attack Control System." At the start of this study for the Bureaus, a PERT chart (Appendix 1) was prepared which outlined the steps, time and manpower requirements necessary to arrive at a well engineered concept for this system. Since both time and funding limitations precluded the complete study as outlined in the PERT chart, it was necessary to rely solely on current SUBIC work to establish the most effective data processing equations. This meant that in some areas detailed studies predicting the performance which could be expected were available, while in other areas, less detailed information on performance was available. The principal reports containing performance information pertinent to this study are as follows:

<u>Fire Control</u>

1) "Mathematical Concepts of the Automatic Statistical Processing Fire Control Computer" - EB report C417-61-011.

2) "Optimal Firing Angles and their Acquisition Probability for a Salvo of Straight Running Torpedoes" - EB report C417-62-014.

Surveillance
3) "Digital Simulation of a Conformal DIMUS Sonar System (Phase II)" - EB report U414-61-010.

Ship Control
4) "Synthesis of a Control System for Automatic Maneuvering of Submarines" - EB report C417-62-019.

Navigation
5) "The N7B Inertial Navigator" - Autonetics Report EM-2140.

In addition to these reports several others are in preparation, scheduled for distribution during Phase VI.

9.2 METHODOLOGY
To arrive at computer characteristics in a logical and orderly fashion Electric Boat has retained Computer Usage Company of New York to perform a three phase study.

Phase I is the definition of the different data processing tasks which must be performed. The source and characteristics of each input to the task, the destination and characteristics of each output from the task, and the processing which must be done to derive the output from the input define the basic characteristics of the task. The frequency or rate at which the processing must be done, inputs sampled, or outputs transmitted must also be known in order to determine the magnitude of the task. The input and output descriptions indicate the "task to task" communications requirements as well as the "man-machine" communications requirements.

Phase II is the determination of the general characteristics which the data processing system must have, based on the specific tasks defined in Phase I. Storage capacity, processing speed, and input/output capability are characteristics which can be estimated. In addition, the following factors can be examined with respect to these tasks and the basic characteristics of the data processing system as it is affected by these factors can be described:

1) <u>Programming implications</u> - What programming and debugging systems must be developed to assist in programming the tasks? Are dynamic simulation techniques necessary to test the system? Will data recording be required for debugging and dynamic simulation?

2) <u>Executive routines</u> - What functions must the executive routines perform (e.g., task scheduling, assignment of priorities, monitoring system, etc)?

3) <u>Input/output system</u> - What types of input/output functions must be performed? Where should program interrupts be used as opposed to programmed input sampling?

4) <u>Controlled degradation</u> - To what extent must the tasks be reallocated upon failure of part of the system? What are the priorities which determine the reallocation?

5) <u>Error restart procedures</u> - How much information must be saved to permit restarting upon detection of an error? What are the priorities which determine the reallocation?

6) <u>Growth</u> - What growth potential must be provided to accommodate additional tasks anticipated by Phase I?

Phase III is an evaluation of three basically different configurations of data processing equipment. The configurations are: a large duplexed system, many independent but intercommunicating systems, and a polymorphic system. This evaluation is made with respect to the above six factors and indicates the effect the specific type of equipment configuration has on each of these factors. Additional factors which are considered in Phase III are:

7) <u>Reliability</u> - How reliable is the equipment configuration likely to be relative to the other configurations? What is the difficulty in locating and repairing failures?

8) Vulnerability - How is the capacity of the system affected by the total or partial failure of a major unit?

9) Error detection - How easily are errors detected? How much programming is required to detect errors?

10) Maintenance - What types of maintenance programs are required? Can diagnostic programs be implemented easily?

11) Task distribution - How should the different tasks be allocated with the system?

12) Costs - What are the relative costs of the alternative systems? What are the programming costs associated with each system?

9.3 STATUS OF THE STUDY

This report represents the results of Phase I of this study and as such will form the problem statement for Phase II of the study scheduled for completion early in August. In the following sections of this chapter, the equations, computational rates, and where applicable, a discussion of the problems involved in effective use of a central computer, for the following data processing functions, have been supplied:

Fire Control

1) Bearing Presmoothing
2) Linear Zig Detection
3) Relative Motion Analysis
4) New Churn Solution
5) Spread Fire Calculations
6) SUBROC Kill Probability
7) Preset Torpedo Equations
8) Wire Guided Torpedo Equations
9) Intercept Torpedo Equations
10) SUBROC Erection and Alignment Equations

Surveillance

11) Stabilization and Destabilization Equations
12) Variable Integration Time Computations
13) Chi-Square Test
14) Chi-Square Time Test
15) Weighted Mean Test
16) Bearing Interpolation
17) Generated Target Track

Ship Control

18) Automatic Control Equations
19) Quickened Control Equations
20) Hovering Equations
21) Digital Filtering

Navigation

22) Loran "C" Fix
23) Star Fix
24) SINS Platform Torquing Computations
25) SINS Fix Computation
26) SINS Three-Position Fix Reset

Command

27) Tactical Display Computations
28) Acoustic Detection Envelope Display

Some of these computational tasks have been analyzed and actually implemented on some type of data processing equipment. Other tasks have been analyzed and programmed for the IBM 704 for detailed study of accuracy, stability, and variation of the solution under different conditions. These tasks can be considered to be well defined and the requirements for their implementation firmly established.

Other tasks have been analyzed superficially so that the requirements for their implementation can only be approximated. Still other tasks

have not been analyzed at all so that it is only possible to make an educated guess at their requirements.

There will inevitably be changes to the tasks as they are now envisioned and other tasks will present themselves as candidates to utilize the capability of a data processing system. The best that this study can hope to achieve is to estimate the order of magnitude of the data processing requirements and to state the assumptions made in arriving at the estimate. An important characteristic of the data processing system is that it be flexible and that it be capable of accommodating the growth and changes which will occur. Thus, even though the size of the data processing requirements may change, the system characteristics determined by this study should not change except that more or less equipment will be required as the size of the tasks are greater or less than estimated. If the order of magnitude of the data processing requirements is changed, however, some of the conclusions drawn from this study may have to be modified.

9.4 PROBLEM AREAS IN DEFINING THE DATA PROCESSING REQUIREMENTS

The list of data processing functions given above is not in any sense a definitive list. Some computational functions such as computer calculated zig plans, although functionally important, will neither materially affect the computer speed nor computer storage characteristics. In cases such as this no attempt has been made to define the actual equations. In cases where the computations are not yet available, but eventual computer calculation is envisioned, such as automatic hovering, equations with similar order-of-magnitude characteristics have been defined as the basis for estimating computer characteristics.

Some of the more important problem areas which could appreciably effect the computer characteristics and hence require further study are:

1) Definition of the hovering, trim and ballast control system.

2) Definition of the number of sensor inputs to the automatic steering and diving control system requiring filtering.

3) Definition of the environmental information which can be displayed at the command console as the basis for tactical decision making.

4) Definition of the processing requirements for PUFFS.

5) Definition of the degree of integration which can be achieved between passive and active computer processing concepts.

6) Definition of an improved wire guided torpedo control concept.

7) Definition of an improved tactical performance criteria.

8) Definition of a tactical communications concept for coordinated attacks.

9) Definition of a technique to obtain localization solutions against maneuvering targets.

9.5 SHIP CONTROL DATA PROCESSING REQUIREMENTS

9.5.1 Introduction

Ship control is exercised through the Ship Control Console at which the operator enters information to be processed by the computer and processed data and sensed data are displayed to the operator. Control signals may be sent to actuate the control mechanisms from the computer or directly from the Ship Control Console.

The five major data processing tasks associated with ship control are:

STEERING
DIVING
HOVERING
TRIM
BALLAST

Of these tasks, steering and diving have been defined sufficiently so that the data processing requirements for their implementation can be determined. A hovering equation has been indicated that provides a good approximation for estimating the computational requirements. Main ballast has been

defined as requiring no computer usage. Trim has not been sufficiently defined to permit evaluation of its processing requirements, although provision has been made on the Ship Control Console for the controls and displays which are anticipated to be required for implementation.

For purposes of determining the data processing requirements associated with trim, it is assumed that the magnitude of this task is approximately equivalent to the steering and diving tasks. Further analysis is necessary in order to verify this assumption.

A minor task which must be performed is the Programmed Maneuvering calculations. Generation of headings and time intervals to be used for own ship zigging requires as input, course-made-good, and percent speed-made-good. The computer can generate random numbers in such a way that the desired course-made-good and percent speed-made-good will be obtained while zigging using the headings and time intervals derived from the generated random numbers. The outputs can be used by both the automatic or manual control systems. Since the calculation does not have to be performed very often, it does not significantly affect the processing load.

9.5.2 Automatic and Quickened Calculations

There are two major calculations which must be performed for ship control. The "automatic" calculations are employed when the particular function is to be controlled by the computer. The "quickened" calculations are employed to assist the operator monitor the automatic control system or are used as the principal aid to the operator for manual control. Each of the functions of steering, diving, hovering, or trim can independently utilize the automatic or quickened calculations depending on the mode of control selected by the operator.

Selection of the mode of operation is done by the operator setting switches on the Ship Control Console. The displays generated depend on the switch settings. The SQUIRE display has three symbols displayed on it: actual course and depth, ordered course and depth, and quickened course and depth. The computer causes the "Actual" symbol

to be positioned at the correct place on the display by processing the course and depth input data. Course data is obtained from the Navigation computations or from the Mark 19 Gyro. Depth data is obtained by processing the pressure gauge output. This output must be filtered and multiplied by a constant to convert it from pressure to depth.

The position of the "Ordered" symbol is controlled by the computer on the basis of inputs from the keyboard on the Ship Control Console, the Joystick using the Joystick Order Button, or computer generated inputs for a Programmed Maneuver. Normally the ordered course and depth are entered through the keyboard. When the Order Button on the Joystick is depressed, the Joystick displacements are sampled at a 40 per second rate and the Ordered symbol moves horizontally and vertically at rates which are proportional to the displacements of the Joystick. When a Programmed Maneuver is called for to cause own ship zigging, the ordered course will be derived by the computer on the basis of the generated random numbers as described previously and the Ordered symbol will be positioned accordingly.

The "Quickened" symbol shows the operator where the submarine will be as a result of existing control action and present ship dynamics. It serves both as the primary information upon which the operator bases his actions when he is using manual control and as an aid to the operator in monitoring automatic control.

9.5.2.1 Steering Mode Selector Switch

The Steering Mode Selector Switch has three positions: Primary, Secondary, and Tertiary. When this switch is in the Primary position, both the automatic and quickened equations are calculated. (See pages 342 through 345 for the automatic and quickened calculations). The computed rudder angle determined through the automatic equations is transmitted to the actuators controlling the rudder. The quickened computation uses the computed rudder angle as the W value in the quickened equation for course. The Quickened symbol is then displayed on SQUIRE.

When the Steering Mode Selector Switch is in the Secondary position, the quickened equations are calculated using the lateral Joystick displacement or the emergency helm position as the W value in the quickened equation for course and the quickened symbol is displayed on SQUIRE accordingly. Those portions of the automatic equations which pertain to steering only are not calculated and thus no signals are sent to the rudder actuator from the computer. The control signals are sent directly from the Joystick to the rudder actuators without passing through the computer.

When the Steering Mode Selector Switch is in the Tertiary position, the quickened equations are calculated using the Joystick displacement; if the emergency power switch is not on "RUDDER" or "ALL", as the W value in the quickened equations for course, and the quickened symbol is displayed on SQUIRE. If the emergency power switch is on "RUDDER" or "ALL", the rudder angle is used as the W value since rudder rate control is being employed. As in the Secondary position, no calculations are performed for the automatic equations as they pertain to steering. The control signals are sent directly from the emergency Helm or Joystick to the rudder actuators without passing through the computer.

9.5.2.2 Diving Mode Selector Switch

The Diving Mode Selector Switch has three positions: Primary, Secondary, and Tertiary. When this switch is in the Primary position both the automatic and quickened equations are calculated. The computed plane angles determined through the automatic equations are transmitted to the actuators controlling the planes. The computed stern plane angle is used as S in the quickened equation for depth and the quickened symbol is displayed on SQUIRE.

When the Diving Mode Selector Switch is in the Secondary or Tertiary position and the emergency power switch is not on "PLANES" or "ALL" the quickened equations are calculated using the longitudinal displacement of the Joystick as the S value in the quickened equation

for depth. If the switch is on "PLANES" or "ALL" the stern plane position is used for S. Those portions of the automatic equations which pertain to diving only are not calculated and no signals are sent from the computer to the planes actuators. The control signals are sent directly from the Joystick to the planes actuators without passing through the computer.

9.5.2.3 Steering and Diving Controls and Displays

The Joystick Override Button permits the operator to instantaneously place both steering and diving control in the Secondary mode without the necessity of changing the positions of the Steering and Diving Mode Selector Switches.

There are several other switches which control different aspects of the calculations performed or information displayed. These switches are described below.

The Maximum Allowable Pitch Angle Selector Switch determines the value of θ_{max} used in the automatic and quickened equations.

The Maximum Allowable Rudder Angle Selector Switch determines the value of $\delta_{r\ max}$ used in the automatic and quickened equations.

The Turning Direction Input buttons associated with the keyboard permit the operator to force the ship to turn to Port or Starboard to arrive at the course he enters through the keyboard. Unless the direction of turn is forced by depressing one of these two buttons, the direction of turn chosen by the computer when steering is in the Primary mode is that direction which will minimize the angle of turn.

The SQUIRE Gain Selector Switch indicates to the computer the scale to be used within the ordered square on SQUIRE for the quickened symbol.

The SQUIRE Depth Scale Selector Switch indicates to the computer the depth scale to be used on the SQUIRE display and is required to properly position the symbols on SQUIRE.

The Emergency Power Control Switch directs emergency power to the planes and/or rudder when it is on. In this case the value used for S in the quickened equation for diving is the stern plane δ_s and the value used for W in the quickened equation for steering is the rudder angle δ_r. When this switch is on the operator has rate control over the control surfaces selected.

The Computer Reject Light comes on to indicate that a keyboard entry was not accepted by the computer. It is turned off when an acceptable entry is made.

The Neutral Trim Angle is the command for the automatic trim system and serves as a bias on the pitch angle used in the automatic and quickened calculations.

The Fairwater to Sternplane Ratio switch indicates the ratio to be used in the diving control equations if it is to be different from a_{18} used in the automatic system.

The Hovering Power Switch energizes the hovering pump and indicates to the computer that the diving mode selector switch now indicates hovering mode.

The Pump Rate switch indicates the pump rate to be used in the hovering control.

9.5.3 Hovering Control

The hovering control has two modes of operation; primary and secondary. The primary hovering is a fully automatic system (equations given on page 340). In secondary mode the joystick serves is the flood-blow control. In both modes a quickened depth is computed and displayed on SQUIRE. Since the quickened equation has not been completely defined, the data processing requirements are assumed to be equivalent to that for the quickened depth in diving control.

Hovering control can be in effect only at zero speed. This implies that no computations of any type need be done for steering and diving when hovering calculations are being performed and vice versa.

9.5.4 Sensor Inputs

The automatic and quickened equations require values of the following variables, other than console inputs, as input to the calculations:

Course	Dept Acceleration
Course Rate	Own Ship Speed
Pitch	Fairwater Plane Angle
Pitch Rate	Stern Plane Angle
Depth	Rudder Angle
Depth Rate	

These variables are displayed on the Ship Control Console in various forms, however, only those forms which influence the computer requirements will be discussed.

Of these variables the course, depth, and speed are displayed in both digital and analog form on the Ship Control Console. The course is obtained from the Mark 19 Gyro or from the Navigations computations. The computer will use course data from one of these sources to drive the digital course indicator. Depth is derived from the sea pressure gauge by multiplication of the sensed pressure by a constant. The computed depth is then used by the computer to drive the digital depth gauge. Similarly, the speed is obtained from the Navigation computation or by multiplying the sensed EM Log input by a constant. The computed speed is used to drive the digital speed indicator.

The stern plane, fairwater plane, and rudder angles are used in the calculations and are displayed on the console but not in digital form. In this case, the angle sensors are used to drive the displays directly and the sensor output are digitized and entered into the computer. The computer uses these values in its calculations but does not drive the angle indicator displays on the console.

The pitch used in the computations can be obtained from the Navigation computations or from a pitch angle sensor. The pitch angle displayed on the console is driven by the sensor directly. The pitch rate displayed on the console is obtained using analog equipment to process the sensor data. The pitch rate used by the computer is derived from the pitch angle input to the computer from the Navigation computations or the pitch angle sensor. Thus the computer must digitally filter the pitch angle input data and differentiate it to derive the pitch rate. The digital filtering process is described on pages 346-348.

The course rate is used in the automatic and quickened calculations but is not displayed on the console. The computer must digitally filter the course input data and differentiate it to derive the course rate. The digital filtering process is described on pages 346-348.

The depth rate and depth acceleration are derived from the depth by digital filtering and computing the first and second derivatives. These values are used by the computer to drive the digital depth rate and acceleration displays and are also used in the automatic and quickened calculations.

9.5.5 Summary of Inputs and Outputs

Operator Inputs - Static

- Steering Mode Selector Switch
- Diving Mode Selector
- Hovering Control Switch
- Joystick Order Button
- Joystick Override Button
- Maximum Allowable Pitch Angle
- Neutral Trim Angle Switch
- Maximum Allowable Rudder Angle
- SQUIRE Gain Selector Switch
- SQUIRE Depth Scale Selector Switch
- Fairwater/Stern Plane Ratio Switch
- Emergency Power Control Switch
- Hovering Pump Rate

Operator Inputs - Dynamic
Keyboard - Desired Course and Depth
Port Turning Direction Indicator
Starboard Turning Direction Indicator
Joystick Displacement
Helm Displacement

Sensed Inputs
Course (from Mark 19 Gyro)
Pitch
Sea Pressure
EM Log
Fairwater Plane Angle
Stern Plane Angle
Rudder Angle

Outputs
Reject Signal (keyboard entry not accepted)
SQUIRE X, Y of Actual Symbol
SQUIRE X, Y of Ordered Symbol
SQUIRE X, Y of Quickened Symbol
Ordered Rudder Angle
Ordered Fairwater Plane Angle
Ordered Stern Plane Angle
Digital Course
Hovering Blow - Flood Rate
Ordered Trim Pump Rate
Trim System Water Routing
Digital - Depth
Depth Rate
Depth Acceleration
Digital - Own Ship Speed

9.5.6 Automatic Control Equations

Constants: $\hat{a}_1$ through $\hat{a}_{22}$, Ucrit

Static Variables: θ_{max} = maximum allowable pitch angle

δ_{rmax} = maximum allowable rudder angle

Dynamic Variables: ψ_d = ordered course (entered via keyboard)

Z_d = ordered depth (entered via keyboard)

Turning direction = (shortest, forced port, forced starboard)

Sensed Variables: δ_f = fairwater plane angle

ψ = course

$\dot{\psi}$ = course rate

Z = depth

$\dot{Z}$ = depth rate

$\ddot{Z}$ = depth acceleration

$\dot{\theta}$ = pitch rate

U = speed

w = normal ship velocity

q = pitch rate (in ship coordinate system)
(Note: the rates are obtained via digital filtering)

Output variables: δ_{rd} = desired rudder angle

δ_{sd} = desired stern plane angle

δ_{fd} = desired fairwater plane angle

Steering Equations: $\psi_e = \psi_d - \psi$

$$K_{\psi 1} = a_1 U^{1/2} + a_2 U$$

$$K_{\psi 2} = a_3/U^{3/2} + a_4/U$$

$$\dot{\psi}_{max} = a_{22} U \delta_{r\,max}$$

$$L = \dot{\psi}_{max} \left[1 - a_1/(K_{\psi 2} U)\right]$$

$$\dot{\psi}_d = \begin{cases} K_{\psi 1}\Psi_e & \text{if } \left|K_{\psi 1}\Psi_e\right| \leq L \\ L & \text{"} \quad K_{\psi 1}\Psi_e > L \\ -L & \text{"} \quad K_{\psi 1}\Psi_e < -L \end{cases}$$

If the operator indicates a forced turn to port or starboard the sign of $\dot{\psi}_d$ is made to be - or + respectively.

$$\delta_{rd} = K_{\psi 2}(\dot{\psi}_d - \dot{\psi})$$

Diving Equations: $Z_e = Z_d - Z$

$$K_1 = U^{1/2}/(a_5 - a_6/U)$$

$$K_2 = U^{1/2}(a_7 - a_8/U)/(a_9 - a_{10}U^{1/2})$$

$$K_3 = (a_{11} - a_{12}U^{1/2})/U^{5/2}$$

$$K_4 = \begin{cases} a_{19}(U - a_{20})^2/\left[1 + (U - a_{20})^2/a_{21}\right] & \text{if } U > \text{crit} \\ (U - a_{20})^2/\left[1 + (U - a_{20})^4/16\right] & \text{if } U \leq U_{crit} \end{cases}$$

$$\dot{Z}_d = \begin{cases} K_1 Z_e & \text{if} \quad |K_1 Z_e| \leq U\theta_{max} - |\dot{w}| \\ U\theta_{max} - |\dot{w}| & \text{if} \quad K_1 Z_e > U\theta_{max} - |\dot{w}| \\ -U\theta_{max} + |\dot{w}| & \text{if} \quad K_1 Z_e < -U\theta_{max} + |\dot{w}| \end{cases}$$

$$M = \begin{cases} \ddot{Z} & \text{if} \quad U \geq U_{crit} \\ -U\dot{\theta} & \text{if} \quad U < U_{crit} \end{cases}$$

$$\delta = K_3 \left[(\dot{Z}_d - \dot{Z}) K_2 - M \right]$$

$$\delta_s' = (a_{14}q + a_{15}\dot{w})/U$$

$$\delta_f' = (a_{16}q + a_{17}\dot{w})/U$$

$$\delta_{fd} = -\delta + \delta'_f Z_e^2 / (Z_e^2 + |Z_{e1}|/2$$

$$\delta_{sd} = a_{18} \left[\delta + K_4 (\delta_{fd} - \delta_f) \right]$$

$$+ \delta_s' Z_e^2 / (Z_e^2 + Z_{e1} /2)$$

where Z_{e1} is the initial depth error.

9.5.7 Quickened Equations

Constants: k_1 through k_{10}

Static Variables: θ_{max} = maximum allowable pitch angle

$\delta_{r\,max}$ = maximum allowable rudder angle

Dynamic Variables: Longitudinal Joystick Displacement
Lateral Joystick Displacement
Helm Displacement
ψ_d = ordered course
Z_d = ordered depth

Sensed Variables:

δ_s = stern plane angle

δ_r = rudder angle

ψ = course

$\dot{\psi}$ = course rate

Z = depth

$\dot{Z}$ = depth rate

θ = pitch

$\dot{\theta}$ = pitch rate

δ_{sd} = stern plane angle } compute from automatic equations

δ_{rd} = rudder angle }

Output Variables:

ψ_Q = Quickened course

Z_Q = Quickened depth

Quickened Course:

$$\psi_Q = -\frac{W}{W_{max}}(\psi_d - \psi) + \psi + k_7\,\dot{\psi}\left|1 - \frac{|\psi_d - \psi|}{360}\right| + k_8 W$$

Quickened Depth:

$$Z_Q = Z + k_1 S + k_2\dot{\theta} + k_3\dot{Z}\left|1 - \frac{|Z_d - Z|}{2000}\right|$$

$$+ (k_4 S + \theta/\theta_{max} + k_5\dot{\theta} - k_6\dot{Z})\left|Z_d - Z\right|$$

Operating Modes:

Steering in Primary mode use $W = \delta_{rd}$ and $W_{max} = k_9\,\delta_{r\,max}$

Steering in Secondary mode use W = lateral Joystick displacement and $W_{max} = k_9\delta_{r\,max}$

Steering in Tertiary mode use W = helm displacement and $W_{max} = k_9\delta_{r\,max}$

Diving in Primary mode use $S = \delta_{sd}$

Diving in Secondary or Tertiary mode use S = longitudinal Joystick displacement.

If the Emergency Power Control Switch is ON, use $W = \delta_r$, $S = \delta_s$, and $W_{max} = k_{10}$.

9.5.8 Hovering Equations

Constants: a_{30} through a_{34}

Dynamic Variables: Z_d = ordered depth

Sensed Variables: Z = depth

$\dot{Z}$ = depth rate

$\ddot{Z}$ = depth acceleration

Output Variables f = signal proportional to desired flood or blow rate.

Hovering Computations: $f_1 = a_{30}\ddot{Z} + a_{31}\dot{Z} + a_{32}(Z_d - Z)$

$$f = \begin{cases} f_1 & \text{if } |f_1| < a_{33} \\ a_{34}\operatorname{sign} f_1 & \text{if } |f_1| \geq a_{33} \end{cases}$$

9.5.9 Digital Filtering

Given a sequence of values $X(T_i)$ at equally spaced increments of time ($T_{i+1} - T_i = \Delta T$ constant), it is necessary to remove noise by filtering the data. A simple form of filtering is to fit a least-square polynomial to the data and use the values of the polynomial as filtered data. If the data to be fitted are $X(T_1)$ through $X(T_n)$, the polynomial takes the form.

$$X(t) = a_o + a_1 t + a_2 t^2 + \dots + a_m t^m.$$

where $t = (T-\bar{T})/\Delta t_T$

The normal equations which must be solved for a_o through a_m are

$$n a_o + a_1 \sum_{i=1}^{n} t_i + \dots + a_m \sum_{i=1}^{n} t_i^{\,m} = \sum_{i=1}^{n} X(t_i)$$

$$a_o \sum_{i=1}^{n} t_i + a_1 \sum_{i=1}^{n} t^2_i + \dots + a_m \sum_{i=1}^{n} t_i^{m+1} = \sum_{i=1}^{n} t_i X(t_i)$$

$$a_o \sum_{i=1}^{n} t_i^m + a_1 \sum_{i=1}^{n} t^{m+1} + \dots + a_m \sum_{i=1}^{n} t_i^{2m} = \sum_{i=1}^{n} t_i^m X(t)$$

Since the value we are interested in using is at time t_n, the polynomial is evaluated for

$$X(t_n) = a_o + a_1 t_n + \dots + a_m t_n^m$$

and the first and second derivatives are given by

$$\dot{X}(t_n) = a_1 + 2A_2 t_n + \dots + m a_m t_n^{m-1}$$

$$\ddot{X}(t_n) = 2A_2 + 6A_3 t_n + \dots + m(m-1) a_m t_n^{m-2}$$

Since the time interval of interest is continuously "sliding along", the value of $\bar{\bar{T}}$ will be constantly changing. By so doing, the sums of powers of t_i remain constant and their values can be precomputed. (In fact, if n is an odd number, the values of t_i are simply integers) The values of $X(t_n)$, $\dot{X}(t_n)$, and $\ddot{X}(t_n)$, can be expressed as linear combinations of the power moments on the right hand side of the normal equations.

As an example let m = 2 and n = 9. The normal equations are

$$9\, a_o + 60 a_2 = \sum_{i=-4}^{4} X_i$$

$$60\, a_1 - \sum_{i=-4}^{4} i X_i$$

$$60\, a_o + 708\, a_2 = \sum_{i=-4}^{4} i^2 X_i$$

thus

$$a_o = (59 \sum_{i=-4}^{4} X_i - 5 \sum_{i=-4}^{4} i^2 X_i)/231$$

$$a_1 = \sum_{i=-4}^{4} i X_i / 60$$

$$a_2 = \left(3 \sum_{i=-4}^{4} i^2 X_i - 20 \sum_{i=-4}^{4} X_i\right)/924$$

and

$$X(t_4) = X(4) = a_0 + 4a_1 + 16\, a_2$$

$$\dot{X}(t_4) = a_1 + 8a_2$$

$$\ddot{X}(t_4) = 2\, a_2$$

To go to the next time interval it is necessary only to recompute the power moments using

$$\sum_{i=-4}^{4} X_{i+1} = \sum_{i=-4}^{4} X_i - X_{-4} + X_5$$

$$\sum_{i=-4}^{4} iX_{i+1} = \sum_{i=-4}^{4} iX_i - \sum_{i=-4}^{4} X_i + 5\, X_{-4} + 4X_5$$

$$\sum_{i=-4}^{4} i^2 X_{i+1} = \sum_{i=-4}^{4} i^2 X_i - 2 \sum_{i=-4}^{4} iX_i + \sum_{i=-4}^{4} X_i - 25X_{-4} + 16X_5$$

Using these new power moments the coefficients are recomputed and the values $X(t_5)$, $\dot{X}(t_5)$, $\ddot{X}(t_5)$ obtained. This technique eliminates the need to resolve the normal equations directly and requires many less arithmetic operations.

The above described technique must be applied to the following variables:

Course and Course Rate
Pitch and Pitch Rate
Depth, Depth Rate, Depth Acceleration

The degree of polynomial used and the number of points in the interval must be selected on the basis of the characteristics of the data being filtered. Further analysis is required to determine these characteristics.

9.5.10 Maintenance and Monitoring

Facilities for detecting errors must be provided in the system. Within the computer this can take the form of duplicate computations, self-checking capability, error-correcting codes, or a combination of these techniques. Since these are characteristics of the computer system being evaluated a fuller discussion of this subject is deferred until Phase III of the study.

The computer can perform certain monitoring functions for other equipment, however. This monitoring can be active, in that the computer can periodically scan through the equipments being monitored to determine that they are functioning properly, or it can be passive in that the computer normally does not interrogate the equipment but waits for an interrupt to occur which is caused by a "failure" signal generated in the equipment which is failing.

In either case the computer will cause an indicator or alarm on a console to be activated so that the operators attention can be drawn to the fact of the failure. It may also be necessary for the computer to alter its computations when certain types of failure occur.

Three sets of lights on the Ship Control Console are associated with the monitoring functions: They are:

Mode Status Panel: The nine lights of this panel indicate Primary, Secondary, or Tertiary modes for steering, diving and trim. They normally reflect the mode of control for each of these functions as selected by the Mode Selector Switches. If, during the computer monitoring, a failure of some part of the system is detected, the computer causes the corresponding indicator light to blink. When the fault is corrected the light blinks at a slower rate to indicate that the system can be used again.

Visual SQUIRE Alarm: This light is turned on to indicate a failure in SQUIRE.

Magnetic Amplifiers: A malfunction in the Fairwater Planes, Stern Planes, or Rudder will cause the corresponding light to come on.

9.5.11 Computational Rates

The calculations for the automatic equations must be performed five times per second. Thus the ships dynamics variables, (course, depth and speed) must be sampled at that rate and control signal outputs to the planes and rudder actuators transmitted at the same rate.

The calculations for SQUIRE must be performed 40 times per second. Inputs to the quickened equations from the Joystick must be sampled at the 40 per second rate and outputs to SQUIRE transmitted at the same rate. Those inputs to the quickened equations which are ship's dynamic variables are sampled at the five per second rate, however.

Outputs to SQUIRE for driving the Actual and Ordered symbols must be 40 times per second.

Since the ships dynamics variables are sampled at a five per second rate, digital filtering of these variables is done at the same rate. Similarly, the digital course, speed, depth, depth rate, and depth acceleration displays are driven at the five per second rate.

9.6 FIRE CONTROL DATA PROCESSING REQUIREMENTS

9.6.1 Conceptual Design of a Fire Control System

9.6.1.1 Man and Machine in Their Proper Perspective

One of the major discrepencies in modern fire control systems which make use of automatic computing machines is the attempt to replace the man by the machine. This approach ignores the fact that much of the information pertinent to the particular fire control situation at hand is qualitative and, therefore, cannot be recognized by the machine.

Information is often not expressed quantitatively either because there is no advantage in doing so, or because the assignment of meaningful numbers is too difficult or not possible within the framework of present knowledge. This does not mean, however, that qualitative information is not important. As an example, consider an urgent situation (qualitative information) which indicates to the man that accuracy must be sacrificed for time. To be more specific, this could mean that a

solution which is based on a maximum target speed and which could be used to fire a spread of torpedoes would be preferred over the more accurate solution of range, course and speed which requires considerably more time.

The seriousness of the aforementioned discrepancy is perhaps best illustrated by the fact that manual plotting systems, which are without question inferior to a machine for processing purely quantitative information, are still being used today. In these systems the qualitative information possessed by the man is used to determine the type of quantitative processing to be used. The results of the quantitative processing are then weighed with additional qualitative information to arrive at a final decision which may be to fire or to try a different approach. Conceptually, the manual plotting systems are sound because they permit the use of all information both quantitative and qualitative.

As long as some of the information is qualitative, only the man can be aware of the overall situation. The machine should, therefore, assume the secondary role of an aid to the man.

9.6.1.2 The Closed-Loop Fire Control System

It may happen that the qualitative information possessed by the man will be improved by the results obtained from processing quantitative information. Thus, for example, threat-evaluation based on the initial data may be improved by the results of the computations performed. The resulting changes in the qualitative information may indicate the desirability of an alternative data processing approach. The fire control system should thus be designed as a closed-loop system in which the the input is affected by the output. This closed-loop property is inherent in the manual plotting systems.

9.6.1.3 Desirable Fire Control Computer Characteristics

It was indicated in the previous sections that the computer should be capable of processing quantitative information by different methods enabling the operator to select the method appropriate to the situation.

The computer could thus be designed and constructed to provide all possible outputs simultaneously. This approach is objectionable for several reasons:

1) it would require an unnecessarily large machine and output panel.

2) the console would be cluttered with output dials, only a few of which would be useful in a given situation.

3) advances in information processing techniques would require major hardware redesign.

These objections can be avoided by employing a general purpose machine and, to a certain extent, a general purpose console. The man would call for the data processing routine(s) appropriate to the immediate situation and the machine would perform only those tasks called for. The machine would thus be controlled by the man. Not only could new data processing schemes be added by the relatively simple addition of a new routine to the computer library, but the new schemes could be evaluated under true operating conditions and revised or discarded as indicated by the results.

9.6.2 Present Status in Quantitative Information Processing Techniques
Research efforts in quantitative processing techniques have been directed toward the development of a group of routines which will permit the implementation of the man-machine concepts of the previous section.

The processing techniques have been divided into three groups:

1) Localization solutions represent those routines which calculate target motion parameters.

2) Ballistic solutions include the routines which calculate the input parameters for the weapons from the localization solutions.

3) Solution quality routines combine the weapon characteristics with 1 and 2 above to compute the hit probabilities.

9.6.2.1 Present Status with Respect to Localization Solutions

Equations have been developed to provide all of the pertinent information derivable from bearing information and any other information which may be available (e.g., target speed estimate from a screw count) when the own-ship track consists of uniform rectilinear motion. The equations constitute a routine called <u>relative motion analysis</u>. This routine provides the earliest possible information from which weapons may be fired or from which qualitative information can be improved. The processing of bearings provides the best statistical estimates of:

1) bearing
2) bearing-rate
3) bearing-acceleration
4) relative angle-on-the-bow
5) relative course
6) ratio of relative speed to initial range
7) minimum target speed

In addition, the routine will provide the target range, course and speed given any one of these. This latter capability is useful in many ways even when a reliable estimate of either range, course or speed is not available. For example, in a situation where the bearings are opening, the entry of a maximum target speed will produce the corresponding maximum target range. Alternatively, the entry of several possible target speeds will result in the corresponding ranges and courses all of which can be geographically displayed on a scope in the form of possible target tracks.

Passive target ranging can be accomplished in a few minutes (depending on the range) from a routine which uses the change in bearing-rate resulting from a change in own-ship cross-line-of-sight speed. The routine does not in itself provide target speed or course, but the range so obtained can be used for torpedo sore[illegible]-fire calculations or as an input to the other routines. Range information early in the tracking period is, of course, extremely helpful to the operator for deciding on the subsequent action. Suppose, for example, the bearing

and bearing drift of a contact indicates a possible threat to the mission. The quick ranging routine could be employed to determine if the target is within torpedo range or SUBROC range. Furthermore, suppose the results indicate a SUBROC range and extreme urgency. Active single-ping techniques could then be used for obtaining the precision range needed for SUBROC. The localization information needed to fire would thus be obtained in a much shorter time than is required to obtain the Mode 2 solution described below.

Mode 2 analysis provides target's range, course and speed from bearing information and any other information which may be available. This solution is ordinarily more precise than that obtained from relative motion analysis, but has the following disadvantages:

1) more time is ordinarily required for the solution

2) no output is provided unless own-ship zigs, or a range, course or speed estimate is entered.

The basic least-square equations used in the Mode 2 routine are similar to the MK 113 Churn equations except in the following respects:

1) the bearing pre-smoothing technique (necessary to reduce the inherent bias in the least-square process) has been improved.

2) speed can be entered separately

3) estimates of range, course or speed are entered along with an uncertainty interval to provide the best solution based on the estimate(s) and the bearing information.

Items 1 and 3 above serve to improve the resulting solution whereas item 2 provides additional flexibility.

Both relative motion analysis and Mode 2 analysis are valid only over those portions of the target's track which consist of uniform rectilinear motion. In order to enable the man to determine if such analysis is valid, a zig detection routine is necessary. Short range zig

detection can be accomplished through a visual inspection of the bearing-time curve. Equations have been developed for long range zig detection out to SUBROC ranges. Some results of the long range zig detector are given in reference (1). Intermediate range (about 5 to 10 miles) zig detection is currently being investigated.

Current efforts are being concentrated on obtaining the mean course and speed of advance of a zigging target (a target which is employing evasive maneuvers). Zig detection represents the first step in this direction. Relative motion analysis coupled with a speed estimate and the zig detector can be used at the shorter ranges. The fire control operator simply generates the target track (presented on the geographic display) through the use of the relative motion routine, resets the relative motion analysis at each point where a zig occurs but retains the entire track so generated. The separate legs of the target track generated in this manner will be somewhat scattered due to the statistical behavior of the original data and, in general, the scatter will increase with range. As a result of this latter situation this approach will be useful only at short ranges.

9.6.2.2 Present Status With Respect to Ballistic Solutions
Equations have been developed for the calculation of the optimum firing angles for one to four acoustic torpedoes using the results of relative motion analysis. Four cases have been considered in which the quality and amount of data varies. The quality of bearing-rate from relative motion analysis is, for example, a function of the tracking time. The cases considered are as follows:

<u>Case I</u> Bearing-rate, Bearing-acceleration and target speed known, but with uncertainty.

<u>Case II</u> Bearing-rate, Bearing-acceleration known, but with uncertainty; target speed less than some upper limit; range greater than some lower limit.

<u>Case III</u> Bearing-rate and target speed known, but with uncertainty; range greater than some lower limit.

Case IV Bearing-rate known, but with uncertainty; target speed less than some upper limit; range greater than some lower limit.

In all of these cases, allowance has been made for the target which attempts to evade the torpedo in the event that the torpedo is detected prior to impact.

Future efforts in this area will be devoted to the addition of the case in which range, course and speed are given and the cases will be extended to include torpedoes with both wire guide and acoustic capabilities.

The torpedo input equations supplied in the next section represent equations suitable for use in the situation where a single torpedo is to be fired at a target with a known range, course and speed. These equations do not make use of the results of the above described equations which greatly extend the conditions under which torpedoes can be fired. The inclusion of the torpedo input equations was primarily for the purpose of computer requirement estimation. It is not likely that the extension of the equations to include the optimum firing angle techniques will greatly affect the computer requirements.

Equations for SUBROC inputs appear as presented in reference(2). No changes are anticipated in these equations at this time.

9.6.2.3 Present Status With Respect to Solution Quality
Equations have been derived for torpedo hit probabilities associated with the four cases above. This work will be extended to include the case where range, course and speed are known and for the combination wire guide and acoustic torpedo when used in either the corrected intercept mode or the bearing-rider mode.

The SUBROC hit probability equations appear as in reference (3).

9.6.2.4 Computer Implications

The preceding general descriptions of the present status of the quantitative information processing techniques have shown that

1) there is a large variety of processing techniques, inputs and outputs not all of which will be applicable in a given situation.

2) the development of new improved processing techniques is at a rapid pace with no indication of a slowing down.

The implications are that it would be extremely desirable, if not necessary, from the fire control aspects to have a processor and associated input-output which is flexible in the sense that it

1) readily permits the operator to call for routines appropriate to the immediate situation

2) allows for the addition of new and improved routines.

9.6.3 Equations

9.6.3.1 Bearing Pre-smoothing (used in Mode 2)

A sequence of bearings, B_i, are observed at times t_i These bearings are averaged over time intervals to produce a sequence of "smoothed" bearings. The minimum number of bearings averaged is N. The maximum length of the interval is determined by one of two criteria, namely, occurrence of significant curvature within the interval or a maximum time (T_{max}) permitted for an interval. The processing consists of the following steps: if $t_n - t_o \geq T_{max}$, compute

$$\bar{B} = \frac{1}{n} \sum_{i=o}^{n-1} B_i$$

$$\bar{B} = \frac{1}{n} \sum_{i=o}^{n-1} t_i$$

use $\bar{t}$, $\bar{B}$ as the smoothed bearing for the interval and start a new interval using t_n as t_o for the new interval. (Since the smallest number of bearings averaged is N, no testing of $(t_n - t_o)$ is done unless $n \geq N$).

If $(t_n - t_o) < \bar{T}_{max}$, the bearing data are tested to see if significant curvature exists. This is accomplished by fitting a second degree polynominal to the data and testing the magnitude of the coefficient of the t^2 term as follows:

The polynomial to be fitted is

$$B = a + b\,(t - t_o) + c\,(t - t_o)^2$$

The coefficient c is determined by solving the equations

$$a(n + 1) + b \sum_{i=o}^{n} (t_i - t_o) + c \sum_{i=o}^{n} (t_i - t_o)^2 = \sum_{i=o}^{n} B_i$$

$$a \sum_{i=o}^{n} (t_i - t_o) + b \sum_{i=o}^{n} (t_i - t_o)^2 + c \sum_{i=o}^{n} (t_i - t_o)^3$$

$$= \sum_{i=o}^{n} B_i\,(t_i - t_o)$$

$$a \sum_{i=o}^{n} (t_i - t_o)^2 + b \sum_{i=o}^{n} (t_i - t_o)^3 + c \sum_{i=o}^{n} (t_i - t_o)^4$$

$$= \sum_{i=o}^{n} B_i\,(t_i - t_o)^2$$

for c. Then compute

$$c_{33} \left[(n + 1) \sum_{i=o}^{n} (t_i - t_o)^2 - \left(\sum_{i=o}^{n} (t_i - t_o) \right)^2 \right] \Big/ |A|$$

where $|A|$ is the determinant of the matrix of coefficients of a, b, and c in these equations. Next compute

$$\sigma_c^{\ 2} = c^2_{33}\ \sigma^2\,B$$

where σ^2_B is the variance of the observed bearings (assumed constant for the present, with provision to enter a new value through the console if desired).

If $\sigma_c/c \geq K$

where K is a preset constant, the bearing data does not have significant curvature and a new t_i, B_i is added to the set of data. If, however,

$$\sigma_c/c < K$$

for three consecutive tests, the data has significant curvature and

$$\bar{B} = \frac{1}{n} \sum_{i=o}^{n} B_i$$

$$\bar{t} = \frac{1}{n} \sum_{i=o}^{n} t_i$$

are computed as the smoothed bearing data for the interval to be used in the Mode 2 solution and a new interval is started using t_n as t_o.

The raw bearing input rate is one bearing every one or two seconds. The minimum number of bearings smoothed is ten (N=10). The maximum number smoothed is 120 to 240 (T_{max} = 4 min.) Thus the maximum output rate of pre-smoothed bearing to Mode 2 is one every 10 sec. and the minimum rate is one every four minutes.

9.6.3.2 Linear Zig Detector

The raw bearings from t_o to t_n are fitted by a straight line using the least square principle. The line fitted is

$$B^* = a' + b'(t - t_o)$$

in which a' and b' are obtained by solving

$$a'(n+1) + b' \sum_{i=o}^{n} (t_i - t_o) = \sum_{i=o}^{n} B_i$$

$$a' \sum_{i=o}^{n} (t_i - t_o) + b' \sum_{i=o}^{n} (t_i - t_o)^2 = \sum_{i=o}^{n} B_i(t_i - t_o)$$

Predicted bearings in the interval t_{n+k+1} through t_{n+k+p} are obtained by

$$B^*_{(n+k+j)} = a' + b' (t_{n+k+j} - t_o) \qquad j = 1, 2, \ldots. p.$$

Matrix A is

$$A = \begin{pmatrix} n + 1 & \sum_{i=o}^{n} (t_i - t_o) \\ \sum_{i=o}^{n} (t_i - t_o) & \sum_{i=o}^{n} (t_i - t_o)^2 \end{pmatrix}$$

and its inverse is

$$A^{-1} = \begin{pmatrix} c'_{11} & c'_{12} \\ c'_{21} & c'_{22} \end{pmatrix}$$

Then compute

$$\sigma_p^2 = \sigma_B^{\,2} (c'_{11}p + c'_{22}T^2 + 2C'_{12}Tp + p)$$

where

$$T = \sum_{i=o}^{p} (t_{n+k+1}) - t_o)$$

and p is the number of predicted bearings.

Define

$$\hat{\Gamma}_p \equiv \left| \sum_{i=1}^{p} (B^*_{n+k+i} - B_{n+k+i}) \right|$$

$$X = \hat{\Gamma}_p/\hat{\sigma}_p$$

The probability of zig, P_z, is given by

$$P_z = 1 - \frac{1}{(1 + 0.2X + 0.12X^2 + 0.2X^4)^4}$$

The quantity P_z is computed every Δt sec. until $t_{n+k+p}-t_{n+k}$ exceeds some criterion Δt_{max}.

Presently, $\Delta t = 10$ sec. and $\Delta t_{max} = 1$ minute. When Δt_{max} is reached, the data for the interval t_{n+1} through t_{n+k} are added to the sums for the interval t_o to t_n and the process is repeated with the new prediction interval starting at $t_{n+k+p+1}$. (Note that interval t_{n+1} through t_{n+k} is Δt_{max} in length).

9.6.3.3 Quick Passive Ranging

Own ship travels on a straight leg from t_o to t_z then changes course and/or speed. The two straight line least square fits from the linear zig detector are used to obtain the quick passive range by solving

$$R = \frac{U_{o_1} \sin\left[Co_1 - B_1^*(t_z)\right] - U_{o_2} \sin\left[Co_2 - B_2^*(t_z)\right]}{b'_2 - b'_1}$$

where U_o = own ship speed

C_o = own ship course

and the subscripts 1 and 2 refer to first and second leg of own ship track.

9.6.3.4 Relative Motion Analysis

During the straight line course between zigs the relative motion analysis yields information about the target ship course. All current bearing data for the leg are utilized in the computations.

The bearing data are fitted by a second degree polynomial of the form,

$$B^* = a + b\,(t - t_o) + c\,(t - t_o)^2$$

using the least square principle. The normal equations are $AX = d$ where

$$A = \begin{pmatrix} n+1 & \sum_{i=o}^{n} (t_i - t_o) & \sum_{i=o}^{n} (t_i - t_o)^2 \\ \sum_{i=o}^{n} (t_i - t_o)^2 & \sum_{i=o}^{n} (t_i - t_o)^2 & \sum_{i=o}^{n} (t_i - t_o)^3 \\ \sum_{i=o}^{n} (t_i - t_o)^2 & \sum_{i=o}^{n} (t_i - t_o)^3 & \sum_{i=o}^{n} (t_i - t_o)^4 \end{pmatrix}$$

$$X = \begin{pmatrix} a \\ b \\ c \end{pmatrix}$$

and

$$d = \begin{pmatrix} \sum_{i=o}^{n} B_i \\ \sum_{i=o}^{n} B_i\,(t_i - t_o) \\ \sum_{i=o}^{n} B_i\,(t_i - t_o)^2 \end{pmatrix}$$

The sums are taken over the entire time interval of the current straight line course of the target ship. These equations must be solved for a, b, and c.

The current bearing (at time t_c) is given by

$$B^*_c = a + b\,(t_c - t_o) + c\,(t_c - t_o)^2$$

the bearing rate by

$$\dot{B}^*_c = b + 2c\,(t_c - t_o)$$

and change in bearing rate by

$$\ddot{B}^*_c = 2c$$

Relative angle on the bow at time t_c is given by

$$\alpha_c = \alpha(t_c) = B^*_c - a + \arctan\,(b^2/c)$$

The quadrant for α_c is determined by analysis of the signs of band c.

The current bearing B^*_c, bearing rate $\dot{B}^*_c$ and relative angle on the bow α_c are displayed on the Fire Control Console in the localization section.

Minimum target speed is given by the following:

$$\eta = C_o - a + \arctan\,(b^2/c)$$

if $\quad \pi/2 \leq \eta \leq 3\pi/2$, then,

$$U_{min} = U_o$$

otherwise $\quad U_{min} = U_o \left|\sin\eta\right|.$

Given a speed estimate U_e, the targets range and course can be found from the following:

$$\eta = C_o - a + \arctan (b^2/c)$$

$$\gamma_j = (j-1)\pi + (-1)^{j-1} \arcsin (U_o \sin \eta / U_e)$$

If

(a) $0 \leq \eta < \pi/2$ or $\frac{3\pi}{2} \leq \eta \leq 2\pi$

and if $U_o > U_e$, then $j = 1$ and 2; $U_e > U_{min}$

(b) and if $U_e \geq U_o$ or $U_e = U_{min}$

then $j = 1$

If $\pi/2 \leq \eta \leq \frac{3}{2}\pi$

then $j = 1$

In all cases $U_e \geq U_{min}$

Target course and range are obtained from

$$C_{tj} = \pi - \gamma_j + a - \arctan (b^2/c)$$

and

$$R_j(t) = b^2 U_j / (c^2 + b^4)^{1/2} (b + c\, t - t_o)$$

in which

$$U_j = (U_o^2 + U_e^2 - 2 U_o U_e \cos (C_{tj} - C_o))^{1/2}$$

Given a range estimate R_e, the target speed and course can be found from the following:

The range estimate is designated by R_e and the time of the estimate by t_e. Target speed is obtained from

$$U_t = \left| (U_x^2(t_e) + U_y^2(t_e))^{1/2} \right|$$

in which

$$U_x(t_e) = U_o \sin \left[C_o - B(t_e) \right] + R_e \left[b + 2c(t_e - t_o) \right]$$

and

$$U_y(t_e) = U_o \cos \left[C_o - B(t_e) \right] - R_e C / \left[b + c(t_e - t_o) \right]$$

Target course is obtained from

$$C_t = B(t_e) + \arctan \left[U_x(t_e) / U_y(t_e) \right]$$

and range at any time (t) is obtained from

$$R(t) = R_e \left[(b + c(t_e - t_o) \right] / \left[b + c(t - t_o) \right]$$

The "Change in bearing rate", $\Delta\dot{B}$, is used by the operator to assist him in making his decisions about target motion.

$\Delta\dot{B}$ is given by:

$$\dot{B}_j = \frac{1}{N} \sum_{i=j+1}^{j+N} (B_i - B_{i-1})/(t_i - t_{i-1})$$

$$\Delta\dot{B}_j = \dot{B}_j - \dot{B}_{j+N}$$

where N is held constant. Thus $\dot{B}_j$ is an average bearing rate over the interval t_{j+1} through t_{j+N}, and $\Delta\dot{B}_j$ is the change in bearing rate as compared to the preceeding interval t_{j-N+1} through t_{j+1}.

Bearings used in the Relative Motion Analysis are those provided by Surveillance processing. The Relative Motion Analysis is performed for legs of the target track which are straight lines, the end of one leg and beginning of another being defined by the Zig Detector calculations described previously. The Fire Control Console has provision for the operator to enter additional data needed by Relative Motion Analysis and displaying the results of the calculations.

9.6.3.5 Mode 2 Solution

The Mode 2 solution results from solving a set of least square normal equations in which the elements of the matrix contain contributions due to observed bearings, estimated range and/or speed and/or course and/or range-rate, and/or continuous range. The normal equations are

$$Ax = d$$

where

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix}$$

$$a_{11} = \sum_i b_{1,i}^2 + \sum_j \rho^2_{1,j} + \mu_1^2 + r_1^2 + s_1^2 + c_1^2$$

$$a_{12} = a_{21} = \sum_i b_{1,i} b_{2,i} + \sum_i \rho_{1,j} \rho_{2,j} + r_1 r_2$$

$$a_{13} = a_{31} = \sum_i b_{1,i} b_{3,i} + \sum_i \rho_{1,j} \rho_{3,j} + \mu_1 \mu_3 + r_1 r_3 + s_1 s_3 + c_1 c_3$$

$$a_{14} = a_{41} = a_{23} = a_{32} = \sum_i b_{2,i} b_{3,i} + \sum_j \rho_{2,j} \rho_{3,j} + r_2 r_3$$

$$a_{22} = \sum_i b^2_{2,i} + \sum_i \rho^2_{2,i} + r^2_2$$

$$a_{24} = a_{42} = \sum_i b_{2,i} b_{4,i} + \sum_j \rho_{2,j} \rho_{4,j} + r_2 r_4$$

$$a_{33} = \sum_i b^2_{3,i} + \sum_j \rho_{3,j}^2 + \mu_3^2 + r_3^2 + s_3^2 + c_3^2$$

$$a_{34} = a_{43} = \sum_i b_{3,i} b_{4,i} + \sum_j \rho_{3,j} \rho_{4,j} + r_3 r_4$$

$$a_{44} = \sum_i b^2_{4,i} + \sum_j \rho^2_{4,j} + r_4^2$$

$$x = \begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{pmatrix}$$

is the vector of unknowns, and

$$d = \begin{pmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \end{pmatrix}$$

where

$$d_1 = \sum_i b_{1,i}\alpha_i + \sum_j \rho_{1,j}\xi_j + \mu_1\eta + r_1\beta + s_1\gamma$$

$$d_2 = \sum_i b_{2,i}\alpha_i + \sum_j \rho_{2,j}\xi_j + r_2\beta$$

$$d_3 = \sum_i b_{3,i}\alpha_i + \sum_j \rho_{3,j}\xi_j + \mu_3\eta + r_3\beta + s_3\gamma$$

$$d_4 = \sum_i b_{4,i}\alpha_i + \sum_j \rho_{4,j}\xi_j + r_4\beta$$

The source of the various terms contributing to the coefficient a_{ij} and d_j are:

b's, α from pre-smoothed bearings
r's, β from estimated range
s's, γ from estimated speed
c's, from estimated course
ρ's, ξ from continuous range observations
μ's, η from range-rate

The individual contributions of the various types of constraints to the normal equation coefficients are kept separately so that solutions for different combinations of constraints may be obtained. Normal equations for solution of up to four targets are maintained simultaneously. After the normal equations are solved for A_1, A_2, A_3, and A_4, the target parameters are determined at time t by

$$R = \left[(A_4 + A_3 t - X)^2 + (A_2 + A_1 t - Y)^2 \right]^{1/2}$$

$$C = \arctan\ (A_1/A_3)$$

$$S = (A_1^2 + A_3^2)^{1/2}$$

$$R_y = A_4 + A_3 t - Y$$

$$R_x = A_2 + A_1 t - X$$

where X, Y is own ships position at time t. The errors in these parameters are given by

$$\sigma_B = \text{constant} = \text{standard deviation of raw bearings}$$

$$\sigma_R = \frac{\sigma_B}{R}\left\{\left[R_x^2 t^2 c_{11} + R_y^2 t^2 c_{33} + R_x^2 c_{22} + R_y^2 c_{44}\right] + 2\left[R_x R_y t(c_{14} + c_{23}) + R_x R_y t c_{13} + R_x^2 t c_{34} + R_x R_y c_{24}\right]\right\}^{1/2}$$

$$\sigma_s = \frac{\sigma_B}{S}\left[A^2 4 c_{11} + A_3^2 c_{33} + 2 A_1 A_3 c_{13}\right]^{1/2}$$

$$\sigma_c = \frac{\sigma_B}{A_1^2 + A_3^2}\left[A_3^2 c_{11} + A_1^2 c_{33} - 2A_1 A_3 c_{13}\right]^{1/2}$$

where the c_i's are lements of the inverse matrix $C = A^{-1}$

Contribution of the Pre-smoothed Bearings to Normal Equations

The pre-smoothed bearing data are of the form $\bar{t}_i$, $\bar{B}_i$, $\bar{n}_i$, where n is the number of values that were averaged to obtain $\bar{t}$ and $\bar{B}$. Their contributions to the normal equation coefficients are

$$W_{Bi} = n_i$$

$$b_{1,i} = \sqrt{W_{B_i}}\,\bar{t}_i \cos \bar{B}_i$$

$$b_{2,i} = \sqrt{W_{B_i}} \cos \bar{B}_i$$

$$b_{3,i} = \sqrt{W_{B_i}}\,\bar{t}_i \sin \bar{B}_i$$

$$b_{4,i} = \sqrt{W_{B_i}} \sin \bar{B}_i$$

$$\alpha_i = \sqrt{W_{B_i}}\,(Y_i \sin \bar{B}_i - X_i \cos \bar{B}_i)$$

where X_i, Y_i is own ships position at time $\bar{t}_i$.

Contribution of Estimated Range to Normal Equations

If an estimate of the range R_e is available at time t_e, the contributions to the normal equations are

$$\sigma_{R_e} = \text{manually entered estimate of the standard deviation of } R_e$$

$$W_{RD} = (R_e\sigma_B / \sigma_{Re})^2$$

$$r_1 = \sqrt{W_{RD}}\, t_e \sin B_e^*$$

$$r_2 = \sqrt{W_{RD}} \sin B_e^*$$

$$r_3 = \sqrt{W_{RD}}\, t_e \cos B_e^*$$

$$r_4 = \sqrt{W_{RD}} \cos B_e^*$$

$$\beta = \sqrt{W_{RD}}(Y_e \cos B_e^* + X_e \sin B_e^* + R_e)$$

where X_e, Y_e is own ships position at time t_e and

$$B_e^* = \arctan\left[\frac{A_2^1 + A_1^1 t_e - X_e}{A_4^1 + A_3^1 t_e - Y_e}\right]$$

is computed using A_1^1, A_2^1, A_3^1, A_4^1 from the previous solution of the normal equations. It is necessary to iterate the solution until the change in B^*_e is insignificant. About four iterations are required for convergence. The value of B^*_e used on the first iteration can be a linerly interpolated or extrapolated bearing obtained from the pre-smoothed bearings.

Contribution of Estimated Speed to Normal Equations.

If an estimate of the speed S_e is available the contributions to the normal equations are

σ_{se} = manually entered estimate of the standard deviation of S_e,

$W_z = (\rho\sigma_B / \sigma_{se})^2$, ρ is a constant,

$S_1 = \sqrt{W_s} \csc C^*/2$, $\quad s_3 = \sqrt{W_s} \sec C^*/2$

$\gamma = \sqrt{W_s} S_e$

where C^* is computed from

$$C^* = \arctan (A_1' / A_3')$$

and A_1', A_3' are obtained from the previous solution of the normal equations. It is necessary to iterate the solution until the change in C^* is insignificant. About four iterations are required for convergence. The value of C^* used on the first iteration can be estimated from some prior solution of the normal equations. (Even an artificial solution).

Contribution of Estimated Course to Normal Equations

If an estimate of the course C_e is available, the contributions to the normal equations are

σ_{ce} = manually entered estimate of the standard deviation of C_e

$W_s = (K_2\sigma_B/\sigma_{se})^2$, K_2 is a constant,

$c_1 = \sqrt{W_c} \cos C_e$

$c_2 = \sqrt{W_c} \sin C_e$

Contributions of Continuous Range Measurements to Normal Equations

If continuous measurements of the range R_j and bearing B_j are available (sampled at discrete times t_j), the contributions to the normal equations are

σ_R = manually entered estimate of the standard deviation of R

$$W_{RC} = (R_j \sigma_B / \sigma_R)^2$$

$$\rho_{1,j} = \sqrt{W_{RC}}\, t_j \sin B_j; \quad \rho_{2,j} = \sqrt{W_{RC}} \sin B_j$$

$$\rho_{3,j} = \sqrt{W_{RC}}\, t_j \cos B_j$$

$$\rho_{4,j} = \sqrt{W_{RC}} \cos B_j$$

$$\xi_j = \sqrt{W_{RC}}(X_j \sin B_j + B_j + Y_j \cos B_j + R_j)$$

where X_j, Y_j is own ships position at time t_j.

Contributions of Estimated Range-Rate to Normal Equations

If an estimated range-rate $\dot{R}_k$ is available, the contributions to the normal equations are;

$\sigma_{\dot{R}}$ = manually entered estimate of the standard deviation of $\dot{R}$

$$W_{\dot{R}} = (R_k \sigma_B / \sigma_{\dot{R}})^2$$

$\mu_1 = \sqrt{W_{\dot{R}}} \sin B_k$ B_k obtained from active sonar

$$\mu_2 = \sqrt{W_{\dot{R}}} \cos B_k$$

$$\eta = \sqrt{W_{\dot{R}}}(\dot{X}_k \sin B_k + \dot{Y}_k \cos B_k + \dot{R}_k)$$

where $\dot{X}_k$, $\dot{Y}_k$ are own ship velocity components.

9.6.3.6 Consort Operations

Consort observations of the target include bearing, time, and if available, range and range rate. These data are entered into the Churn solution as additional data and thus are included in the normal equations as though they had been observed by own ship.

Since the X, Y position of the consort is required, the range and bearing to own ship from consort are transmitted to permit calculation of the consorts position.

9.6.3.7 Spread Fire Calculations and Torpedo Hit Probabilities
In order to evaluate the assignment of a torpedo to a target it is necessary to calculate the kill probability. A salvo of up to four torpedoes can be fired at a target and the firing angles and associated kill probabilities must be known.

These calculations vary depending on the amount of data available. In some cases the target speed is known while in others, only an upper limit on the speed is known. Similarly, the range may be known, or only an estimate of the minimum range may be known.

The four Cases considered are:

<u>Case I</u> $\ddot{B}$ and S_{TA} = target speed, known with error.

<u>Case II</u> $\ddot{B}$ known with error, S_{TA} less than some upper limit $\bar{S}_{TA}$. R greater than some lower limit $\underline{R}$.

<u>Case III</u> $\ddot{B}$ Unknown, S_{TA} known with error, R greater than some lower limit $\underline{R}$.

<u>Case IV</u> $\ddot{B}$ Unknown, S_{TA} less than some upper limit $\bar{S}_{TA}$, R greater than some lower limit $\underline{R}$.

Values of α_i, U_{ij}, P_{ij} are computed for each of these four cases and used in later calculations. The following indicates the calculations required for each case:

Case I

$$\alpha = \arctan\,(2\dot{B}^2/\ddot{B})$$

$$n = 2F_1F_2 + 1$$

$$\alpha_i = \alpha + (i - 1 - F_1F_2)\sigma_\alpha/F_1 \qquad i = 1, 2, \ldots, n$$

$$S_j = S_{TA} + (j - 1 - F_1F_2)\sigma_s/F_1 \qquad i = 1, 2, \ldots, n$$

$$S_{os} = \text{own ships speed}$$

$$\mu_{ij} = -S_{os}\sin\,(\alpha_i - B) \pm \sqrt{S_j^2 - S_{os}^2\cos^2\,(\alpha_i - B)}$$

$$P_{ij} = \exp\left[-\ \tfrac{1}{2}(i - 1 - F_1F_2)^2/F_1^2 - \tfrac{1}{2}(j - 1 - F_1F_2)^2/F_1^2\right]$$

Case II

n, α_i as in Case I

$$\bar{u} = -S_{os}\sin\,(\alpha - B) + \sqrt{(\bar{S}_{TA})^2 - S_{os}^2\cos^2\,(\alpha - B)}$$

$$\bar{R} = \bar{u}\,\sin\alpha/\dot{B}$$

$$R_j = \underline{R} + (j - \tfrac{1}{2})(R - \underline{R})/n$$

$$u_{ij} = R_j\dot{B}/\sin\alpha_i$$

$$P_{ij} = \left\{\exp\left[\tfrac{1}{2}(i - 1 - F_1F_2)^2/F_1^2\right]\right\}\left[U_o + U_1R_j + U_2R_j^2 + U_3R_j^3\right]$$

Case III $\quad n$, $\hat{S}_j$ and u_{ij} as in Case I

$$\hat{\alpha}_i = \left[(i - \tfrac{1}{2})\pi/n \right] \text{sign } \dot{B}$$

$$\hat{R}_{ij} = u_{ij}\sin \alpha_i/\dot{B}$$

$$P_{ij} = \left\{ \exp\left[- \tfrac{1}{2}(j - 1 - F_1F_2)^2/F_1^2 \right] \right\} \left[U_0 + U_1R_{ij} + U_2R^2_{ij} + U_3R_{ij}^3 \right] \left| R_{ij} - R_{i-1,j} \right|$$

Case IV $\quad n$ as in Case I

$\hat{a}_i$ as in Case III

$\underline{S} = S_{os}\cos B \text{ sign } \dot{B}$ (if $\underline{S} < o$, set $\underline{S} = o$)

$$\hat{S}_j = \underline{S} + (j - \tfrac{1}{2})(\bar{S} - \underline{S})/n$$

U_j = as in Case I

$R_{ij} = P_{ij}$ as in Case III

Firing angles, β, are determined by solving

$$T\, u_{ij}\sin \alpha_i = (T + \Delta)\, S_{TO}\sin\beta$$

$$R_{ij} - T\, u_{ij}\cos \alpha_i = (T + \Delta)\, S_{TO}\cos\beta$$

for T and β at the points

$$(a,b) = (1,1)\ (1,n),(n,1),(n,n),(1 + F_1F_2,\ 1 + F_1F_2).$$

The torpedo speed $\hat{S}_{TO} = -S_{os}\sin(B + \beta) + \sqrt{\left[S_{os}\sin(B + \beta)\right]^2 - S_{os}^2 S_{TO}'^2}$

where S'_{TO} is the approximate torpedo speed and $\hat{S}_{TO}$ is the corrected torpedo speed. The equations for T, β must be re-solved using the corrected torpedo speed and the new β used to get a new corrected torpedo speed. This cycle is repeated until $\hat{S}_{TO}$ and β are stabilized. The time of the targets detection of the torpedo, t_D, is found by solving

$$X_{ij}(t) = t(u_{ij}\sin\alpha_i - S_{TO}\sin\beta_{ab})$$

$$Y_{ij}(t) = R_{ij} - t(u_{ij}\cos\alpha_i + S_{TO}\cos\beta_{ab})$$

$$X_{ij}(t)^2 + Y_{ij}(t)^2 = D^2$$

for t where

D = detection distance

β_{ab} = one of the five firing angles

Analysis of the two roots obtained indicates where the torpedo can acquire the target.

The time at which target starts evasion maneuvers, t_r, is given by

$$\Delta t = \left[2500 - S_{TA}(110 - 2S)\right]/(100S), t_r = t_D + \Delta t$$

Acquisition in the interval $0 < t < t_r$ is determined by solving the following:

$$X(0) = X_1 = 0$$

$$Y(0) = Y_1 = R_{ij}$$

$$X(t_r) = X_2 = t_r(u_{ij}\sin\alpha_i - S_{TO}\sin\beta_{ab})$$

$$Y(t_r) = Y_2 = R_{ij} - (u_{ij}\cos\alpha_i + S_{TO}\cos\beta_{ab})$$

Simultaneously solve

$$y = \left[(y_2 - y_1)(x - x_1)/(x_2 - x_1)\right] + y_1$$

with

$$x^2 + y^2 = (\rho')^2$$

For roots x', x". If x' or x" lies between X, and X_2 solve

$$y = \left[(y_2 - y_1)(x - x_1)/(x_2 - x_1)\right] + y_1$$

simultaneously with

$$y = x \cos (\beta_{ab} - \gamma)$$

and

$$y = x \cos (\beta_{ab} + \gamma)$$

to determine if there is an intersection in the range X_1 to X_2. If not, find y', y'' from x', x'' and test further by determining if

$$\begin{aligned}(\rho')^2 \sin 2\gamma = &\Big[y' \sin (\beta_{qb} - \gamma) - x' \cos (\beta_{ab} - \gamma)\Big]\Big[x' \sin (\beta_{ab} + \gamma) \\ &+ y' \cos (\beta_{ab} + \gamma)\Big] + \Big[x' \cos (\beta_{ab} + \gamma) \\ &- y' \sin (\beta_{ab} + \gamma)\Big]\Big[x' \sin (\beta_{ab} - \gamma) + y' \cos (\beta_{ab} - \gamma)\Big]\end{aligned}$$

or

$$x' \sin (\beta_{ab} - \gamma) + y' \cos (\beta_{ab} - \gamma) \neq 0$$

where x'; y' are the roots of the solution of the quadratic equation above. A similar test is applied to x'', y''. Acquisition in the interval $t_r < t < t_p$ is determined by the following:

t_ρ = time at which torpedo fuel runs out

$$r(t) = 100 \bar{S} (t - t_D - >t) + S_{TA} (110 - 2\bar{S}) - 2500$$

$$x_c(t_\rho) = x(t_r) - \left[x_{TO}(t_\rho) - x_{TO}(t_r)\right]$$

$$y_c(t_\rho) = y(t_r) - \left[y_{TO}(t_\rho) - y_{TO}(t_r)\right]$$

$$x_{\ell m} = x_c + r(t_\rho)(2\ell - 1 - K)/K$$

$$y_{\ell m} = y_c + r(t_\rho)(2m - 1 - K)/K \qquad \ell, m = 1, 2, \ldots, K$$

if $\quad (x_{\ell m} - x_c)^2 + (y_{\ell m} - y_c)^2 \geq r(t_\rho)^2$

omit the point.

These computations are performed for each of the five firing angles to determine the number of intersections. Then the acquisition probability $A(i,j)$ is determined by the ratio of the number of intersections with the cone of target positions to the possible intersections before t_ρ.

Also compute

$$A(\beta_{ab}) = \Sigma(A_{ij}P_{ij})/\Sigma P_{ij}$$

The best firing angle is determined by analyzing the five selected firing angles. These angles are sorted according to size so that

$$\beta_1 < \beta_2 < \beta_3 < \beta_4 < \beta_5$$

Divide the curve of $A(\beta)$ vs. β into $H_2 + 1$ sections. Choose at random an integer $0 \leq H_1 < H_2$. Then compute

$$\phi = (H_1 + 1/2)/(H_2 + 1)$$

Determine $\phi_{h'}$ and $\phi_{h'+1}$, such that

$$\phi_{k} < \phi < \phi'_{h+1}$$

where

$$\phi_{k'} = W_{k'}/W_5$$

$$W_{k'} = \sum_{i=2}^{k'} 1/2(\beta_i - \beta_{i-1}) \left[A(\beta_{k'}) - A(\beta_{i-1})\right]$$

W_5 is the integral to β_5

Let $$S_{h'} = (A_{h'+1} - A_{h'})/(\beta_{h'+1} - \beta_{h'})$$

The optimum firing angle β' is given by

$$\beta' = \frac{1}{2a_1}\left[-a_2 + \sqrt{a_2^2 - 4a_1a_3}\right]$$

where

$$a_1 = \frac{1}{2} S_{h'}$$

$$a_2 = A_{h'} - S_{h'} \beta_{h'}$$

$$a_3 = \beta_{h'} \left(\frac{1}{2} \beta_{h'} S_{h'} - A_{h'}\right) - (\phi - \phi_{A'}) W_5$$

For a successive torpedo in the salvo, the same calculations must be performed except that all times are referred to the firing time of the first torpedo. Those portions of the computations already done for preceeding torpedoes need not be repeated.

9.6.3.8 SUBROC Kill Probability

The kill probability for SUBROC is given by

$$K_p = \phi \left(\frac{K}{e}\right) - \phi \left(- \frac{K}{e}\right)$$

where

ϕ is the distribution function of a variable having zero mean and unit standard deviation,

K = kill radius of missile

e = error in target range

9.6.3.9 Ballistic Equations

After a weapon has been assigned to a target it is necessary to compute the functions which must be set into the weapon to direct it to the target. In the case of preset torpedoes these calculations are done once and the weapon fired. Wire-Guided torpedoes in the Intercept mode require calculations similar to the preset torpedoes. When the target maneuvers and the W/G torpedo course must be changed, the computer must determine corrections which are then automatically transmitted to the torpedo. Wire-Guided torpedoes fired in the Bearing Rider mode require that corrections be computed continuously and transmitted to the torpedo. SUBROC requires continuous calculations prior to firing, but no calculations after firing.

9.6.3.9.1 Preset torpedo equations

Constants: U_m, $J(U_m)$; Y'_m, $f(H_{vm})$, R_{h3}, $s_J(H_m)$,

$\sin L_{yp}$, K, K_1, T_d, B_g, P_{do}, P_{dn}, P_{vo}, DC_o

Input Variables:

R_h = range to target
B_y = bearing to target
C_t = target course
DM_{ht} = target speed
} from Fire Control calculations

L_{y2} = latitude of firing
C_o = own ship course
H_{vo} = own ship depth
} from Navigation computations

H_{vm} = torpedo run depth (target depth)
$s_q(H_m)$ = enabling run offset
$s_q(G)$ = angular spread
H67 = linear spread
} manually entered quantities

Output Variables:

H_{vm} = torpedo run depth
G = gyro angle
$c(H_m)$ = Com. torpedo path length (run to burst)

Preset Equations:

1. $B = B_y - C_o$
2. $B_{ts} = 180° - (C_t - B_y)$
3. $G = B_{b6} + B - B_g + sq(G)$
   (Assume $B_{b6} = 0$ for first iteration)
4. $H_{vg} = H_{vo} + P_{vo}$
   $H_{vmg} = H_{vm} - H_{vg}$

$H_{vmg_{Rh3}} = (K)(H_{vmg})$

Let $R_{h3} = R_{h3} + H_{vmg_{Rh3}}$

5. $\Sigma x = P_{do}\sin B - P_{dn}\cos B + R_{h3}\sin (B - B_g)$
$- Y_m'\cos(B - B_g) + Y_m'\cos B_{b6} + \Big[(DM_{ht})(T_{26})$
$+ H_{67}\Big]\sin B_{ts}$

6. $\Sigma y = R_h - P_{do}\cos B - P_{dn}\sin B - R_{h3}\cos (B - B_g)$
$- Y'_m \sin (B - B_g) - Y'_m \sin B_{b6} - \Big[(DM_{ht})\ (T_{26}) +$
$+ (H_{67})\Big]\cos B_{ts}$

7. $H_{m26p} = \Sigma x \sin B_{b6} + \Sigma y \cos B_{b6} + R_{h3} + \pi \frac{Y'm}{180} G$

8. $c(H_m) = H_{m26p} + sq(H_m)$

9. $H_{vmg_{c(H_m)}} = K_1 H_{vmg}$

10. $H_{m_{corr}} = -\Big[sj(H_m) + H_{vmg_{c(H_m)}} + (H_{vmg_{c(H_m)}})^2 \Big]$

11. $T_{26} = \dfrac{c(H_m) + H_{m_{corr}}}{U_m + j\ (U_m) + r\ (H_{vm})}$

12. $e(B_{b6}) = \Sigma x \cos B_{b6} - \Sigma y \sin B_{b6} + c(H_m)\Big[-(D_{co})(T_d)$
$+ \frac{1}{2} T_{26}k(\sin L_{yp} - \sin L_{y2}) \Big]$

13. Let $B_{b6} = B_{b6} - e(B_{b6})$ and, start next iteration with equation 3.

9.6.3.9.2 W/G torpedo equations

Constants: U_m, $J(U_m)$, Y'_m, $f(H_{vm})$, R_{h3}; $s_J(H_m)$

$q(H_m)$; L_{yp}; K; P_{do}, P_{dn}, B_q, P_{vo}

Input Variables:

R_h = range to target		from Fire Control Calculations
B_y = bearing to target		
C_t = target course		
DM_{ht} = target speed		
B_2 = initial target bearing		
L_{y2} = latitude of firing		from Navigation Computations
C_o = own ship course		
DM_{ho} = own ship speed		
H_{vo} = own ship depth		
$s_q(G)$ = angular spread		manually entered quantities
$q(C_m)$ = steering order		
H_{vm} = torpedo run depth (target depth)		
$sq(H_m)$ not significant for W/G torpedo		
H67 not significant for W/G torpedo		

Output Variables:

H_{vm} = torpedo run depth		Initial Outputs
G = gyro angle		
$c(H_m)$ = Com. torpedo path length		
$e(G)$ = gyro angle error		Intercept Mode
$e(H_{m7})$ = remaining run to burst error		
$e(G) = e(B_y - B_{my})$ = gyro angle error		Bearing rider Mode
$e(H_{m7})$		

9.6.3.9.3 Intercept Equations

The following quantities, valid at the initial predicted impact point, are generated by the Preset Torpedo Equations: B_{b64}, T_{26}, G, B, $c(H_m)$. These quantities are subsequently utilized in the generation of the correction quantities, $e(G)$ and $e(H_{m7})$, required to compensate for errors in the predicted impact point due to target maneuvering. B_{b64} is taken as a first approximation in the iterative solution for B_{b6}; also, the following substitutions are made $T_4 = T_{26}$; $H_{m7} = c(H_m)$.

The following equations must be evaluated when a target maneuver necessitates recomputing the intercept point:

1. $Y_4 = P_{do}\cos B_2 + P_{dn}\sin B_2 + R_{h3}\cos(B_2 - B_g) + Y_m'\sin B_{b64}$
$$+ Y_m'(\sin B_2 - B_g)$$

2. $X_4 = P_{do}\sin B_2 - P_{dn}\cos B_2 + R_{h3}\sin(B_2 - B_g) + Y_m'\cos B_{b64}$
$$- Y_m'\cos(B_2 - B_g)$$

3. $B_{tm} = C_o + B_2 - 90^\circ$

4. $R_{h4y} = Y_4\sin B_{tm} - X_4\cos B_{tm}$

5. $R_{h4x} = Y_4\cos B_{tm} + X_4\sin B_{tm}$

6. $C_{mo4} = B_{b64} + B_2$

7. $C_{m4} = C_{mo4} + C_o$

8. $j(C_m) = \int_{t_2}^{t} (K/2)(\sin L_{yp} - \sin L_{y2})dt$

9. $C_{ma} = C_{m4} + q(C_m) - j(C_m)$

10. $U'm = U_m + f(H_{vm}) + j(U_m)$

11. $B_{ts} = 180^{\circ} - (C_t - B_y)$

12. $M_{hox} = \int_{o}^{t} D_{mh_o} \sin C_o dt$

13. $M_{hoy} = \int_{o}^{t} D_{mh_o} \cos C_o dt$

14. $R_{hmx} = R_{h4x} - M_{hox} + \int_{t_4}^{t} U'm \sin C_m dt$

15. $R_{hmy} = R_{h4y} - M_{hoy} + \int_{t_4}^{t} U_m' \cos C_m dt$

16. $Y_m = R_{hmx} \sin B_y + R_{hmy} \cos B_y$

17. $X_m = R_{hmy} \sin B_y - R_{hmx} \cos B_y$

18. $\Sigma Y = R_h - Y_m - DM_{ht} T_r \cos B_{ts}$

19. $\Sigma X = X_m + DM_{ht} T_r \sin B_{ts}$

20. $e(B_{b6}) = \Sigma X \cos B_{b6} - \Sigma Y \sin B_{b6}$

21. Let $B_{b6} = B_{b6} + e(B_{b6})$ and if necessary begin next iteration in solution for B_{b6} with equation 1

22. $H_{m6} = \Sigma X \sin B_{b6} + \Sigma Y \cos B_{b6}$

23. $T_r = \dfrac{H_{m6}}{U_m + g(U_m) + f(H_{vm})}$

24. $H_{m7} = e(H_m) + q(H_m) - \int_{t_2}^{t} U_m' dt$

25. $e(H_{m7}) = H_{m7} - H_{m6}$

26. Let $H_{m7} = H_{m7} + e(H_{m7})$

27. $C_{mt} = B_{b6} + B + C_o$

28. $e(G) = C_{ma} - C_{my}$

Bearing Rider Equations: The output quantities required in the Bearing Rider Mode are obtained by using the "Intercept Mode Equations" as described below.

Equation 1 through 21 are solved in conjunction with equation 29 to obtain $e(B_{my})$. The quantity $(C_o + B_q)$ is used as a first approximation to B_{my}.

29. $e(B_{my}) = R_{hmy} \sin B_{my} - R_{hmx} \cos B_{my}$

$e(H_{my})$ is calculated as described for the Intercept Mode.

9.6.5.9.4 SUBROC equations

The approach taken to the SUBROC calculations is to consider only those equations which are computed by the digital computer. The calculations performed by the Missile Weapon Order Equipment and the Analog Computer are assumed to be unchanged.

Constants: R_k, E_f, DIK, DUK, K_4, B_{dg}, B_g

$f_1(R_h)$, $f_2(R_h) f_3(R_h)$, $f_4(R_h)$, $f_5(R_h)$

Input Variables:

from Fire Control solution:
- R_h = target range
- B_y = bearing to target
- C_{qt} = target course
- U_{ht} = target speed

- B = relative bearing to target
- $B=B_g$ = relative target bearing from tube (missile quantity)

from Navigation solution:
- H_{vo} = own ship depth
- L_{yo} = own ship latitude
- U_{ho} = own ship speed-horizontal
- U_{vo} = own ship speed-vertical

	E_{10} = pitch	from Navigation solution
	Z_o = roll	
Output Variables:	P_{vm}	
	P_{srm}	
	U_{jm}	
	U_{vm}	
	U_{rm}	
	U_{srm5}	
	T_f	
	P_{jm}	
	$E_{mt'}$	
	$B_{mt'}$	
	$B-B_g$	
	H_{vo}	

SUBROC Equations:

1. $P_{vm} = H_{vo} - R_h^2/2R_k$

2. $P_{srm} = R_h \cos E_f + f_5(R_h) \cos E_f + H_{vo} \sin E_f$
   $- (R_h^2/2R_k)^5 \sin E_f$

3. $U_{jm} = (DIK)(R_h) \sin L_{yo} - (DUK)(T_f)^2 \cos L_{yo} \cos B_y/6$
   $- U_{ht} \sin (C_{qt} - B_y) - U_{ho} \sin B$

4. $U_{vm} = - (DTK)(R_h) \cos L_{yo} \sin B_y - (K_4)(T_f) \cos 2L_{yo}$
   $- f_2(R_h) + U_{vo}$

5. $U_{rm} = f_1(R_h) + (DUK)(DIK)(T_f)^2 \cos L_{yo} \sin B_y/6$
   $+ U_{ht} \cos({}_{qt} - B_y)$

6. $U_{srm5} \equiv f_3(R_h)$

7. A/K Time - $T_f \equiv f_4(R_h)$

8. $P_{jm} \equiv 0$

9. $$E_{mt}' \equiv \arctan \left\{ \frac{\cos B \sin E_{1o} \cos Z_o - \sin B\, Z_o}{\left[(\cos B \sin E_{1o} \sin Z_o + \sin B \cos Z_o)^2 + (\cos B \cos E_{1o})^2 \right]^{1/2}} \right\}$$

10. $$E_{mt}' \equiv \arctan \left\{ \frac{\cos B \sin E_{1o} \sin Z_o + \sin B \cos Z_o}{\cos B \cos E_{1o}} \right\} + B_{dg}'$$

9.7 SONAR-SURVEILLANCE DATA PROCESSING REQUIREMENTS

During the course of this study, four major functional areas in sonar surveillance were considered. The study had a dual objective: First. "Could a high capacity central processor be used to improve performance of the surveillance system in each of the functional areas?" and second, if potential improvements were indicated "What processing would be required to realize this improvement in performance?" The four functional areas considered were as follows:

1) Passive detection, consisting of the sub-functions; initial indication, post-detection integration; and confirmation of presence of a legitimate target.

2) Passive classification, consisting of analysis of acoustic information in both time and frequency domains to assign the unknown emitter as belonging to a given set or subset of known emitters.

3) Passive tracking, consisting of the process of spatial localization of the noise source, carried out by various tracking routines or by cross correlation routines involving (a) phase comparison of split beams (now done by analog equipment), (b) wave bearing interpolations or (c) wave front curvature calculations.

4) Active processing presently carried out by special purpose analog equipment with no decision-making capabilities inherent in its design.

The study has proceeded to varying stages of completeness in each of the four areas. Briefly, it was found that the central processor could be used quite effectively toward improving initial detection and post detection confirmations. In the classification area it was found that the high rates and large storage requirements necessary for obtaining power spectral estimates indicated the need for special purpose processing equipment. The possibility of filtering out own ship noise prior to the generation of target spectrums does exist, however, and will be explored further during the next phase of this study. In the area of target tracking it was found that computer processing would be effective in (a) storing and updating the predicted bearing of detected targets (b) interpolating between the preformed beams of a DIMUS type system to obtain ATF information (c) stabilization of bearings in the ATF mode when using spherical sonar and (d) cross correlation to obtain passive ranges (wavefront curvature calc.).

The application of the central processor to the active sonar area was not explored to any great extent since considerable work has been done in this regard at NEL. (Small Ship Combat Data System, Volume II, SPADE, NEL/Report 1068).

The following sections summarize the present status of the data processing requirements for passive detection, passive classification and passive tracking. Reference to the NEL report is suggested for the data processing requirements in the area of active sonar.

9.7.1 Passive Detection

In order to enhance the detection capability of the surveillance system an increase in processing flexibility was added to the basic DIMUS concept. This scheme provides for variation in signal integration times, selective filtering of the incoming signal, selection of alternative D/E angles and statistical testing to supplement the conventional aural and visual detection displays. A description of the displays and controls required to implement this concept is discussed in the chapter on the Surveillance Console. The Surveillance Console has provision for displaying the integrals and statistical test data

for broadband analysis for a variety of conditions. The operator can elect to display the integrals for any D/E angle, the best D/E angle, or all three superimposed.

The statistical tests take the form of a "window" for the set of bearings being tested. The Chi-square (or weighted-mean) values are computed only for the beams within the window. About 10-20 points should be included in the window. The window then sweeps across the display so that 360° are swept in one minute. This sweeping continues automatically until the operator alters it. He can position the cursor at a bearing thus causing the window to be centered on that bearing. The window will remain in the selected position for a predetermined length of time (30 sec. - 2 min.) and then resume the automatic sweeping. The values displayed in the window are the test values, while the values on the rest of the line of the display are the integrated R values. The operator selects which statistical test is to be done and displayed by depressing the appropriate button. The nature of the DIMUS system lends itself particularly well to statistical testing since the expectancy for pure uncorrelated noise is predictable.

The narrowband portion of the display shows the R values for all four of the narrow bands superimposed. The operator can elect to display each band individually. The display automatically returns to the superimposed mode after a predetermined length of time. He can also elect to have the computer do an automatic comparison of the R values for the 4 different bands and display only the best band. No statistical tests are performed on the narrow band data.

In order to implement the above detection concept four data processing programs are required. These programs are discussed in the following sections:

9.7.1.1 Variable Integration Time

Three integration times are proposed for the detection system; .1$^{\text{m}}$, 1 and 3 minutes. For purposes of estimating data processing requirements, it is assumed that the preformed beam system will consist of about 180 beams total, disposed equally in 3 D/E angles.

Raw data from these beams must be processed in parallel. The data input rate is too fast for a computer to do even the simple summations required for the integration. It is planned that some type of accumulator register be established for each beam. The contents of these registers are transmitted to the computer every 0.1 sec. and the registers cleared for further accumulations.

The 180 sums received every 0.1 sec. provide the basis for the integration. The 0.1 sec, integral is given by

$$R_{0.1} = \frac{1}{R_{max} I} \Sigma_{0.1}$$

where

$R_{0.1}$ is the 0.1 sec. detected integral for one beam

R_{max} is the maximum diagonal read-out value, a constant.

I is the number of full wave detected data values summed $(I = 2500) = \frac{.1}{40 \times 10^{-6}}$

$\Sigma_{0.1}$ is the sum of I data values in the 0.1 sec. interval; these are full wave detected values.

The $R_{0.1}$ values for each beam are used to drive the display on the Surveillance Console. Three depression/elevation angles are superimposed on each other on the display. The operator can elect to display any of the th ee angles alone by depressing a button on the console. The display automatically returns to the superimposed display after 2 minutes. The operator can also elect to display the best D/E angle based on the largest R obtained.

The $\Sigma_{0.1}$ values are retained in memory until 600 of them have been entered. The sum of these 600 values is in effect a sum over a 1 minute interval. The 1 minute integral can then be computed by

$$R_{1.0} = \frac{1}{R_{max} J} \Sigma_{1.0}$$

where J is the number of data values in $\Sigma_{1.0}$ $(J = 1{,}500{,}000 = 2500 \times 600)$, $R_{1.0}$ is recomputed and transmitted to the display every 6 seconds. The

first 60 terms of the $\Sigma_{1.0}$ sum must be dropped and 60 new terms added every 6 seconds. By retaining sums of 60 values, 10 such sums make up the one minute sum, thus reducing the storage requirements to 10 values per beam.

Similarly, the 3.0 minute integration represents sums of 3 minutes of data and

$$R_{3.0} = \frac{1}{R_{max}K} \Sigma_{3.0}$$

where K is the number of data values in $\Sigma_{3.0}$ (K = 4,500,000 = 1,500,000 x 3). The $\Sigma_{3.0}$ sum must be recomputed and displayed every 18 sec. Thus, by keeping sums of 180 detector outputs, 10 such sums make up the three minute sum.

Each beam is processed in the same way. The integration time for which data is to be displayed on the console is selected by the operator.

9.7.1.2 Chi-Square Calculation

The Chi-Square value $X^2(\theta_1)$ for a particular pre-formed beam θ_1 is defined by

$$X^2(\theta_1) = \sum_{j=J}^{J} \left[\bar{E} - \bar{R}\ (\theta_{1+j}) \right]^2 / \bar{E}$$

where $R\ (\theta_{1+j})$ is the integrated detected output for the diagonal associated with beam θ_{1+j}. $\bar{E}$ is the theoretical detector output with no target. For full wave linear detectors the value of $\bar{E}$ is given by

$$\bar{E}(R) = \frac{1}{T} \sum_{n=0}^{T} \left(\frac{1}{2}\right)^T C(\bar{T},n) \left| T - 2n \right|$$

and for full wave square law detectors it is given by

$$\bar{E}(R) = \frac{1}{T} \sum_{n=0}^{T} \left(\frac{1}{2}\right)^T C(\bar{T},n)(\bar{T} - 2n)^2$$

$X^2(\theta_i)$ is calculated for every beam and the resulting set of values normalized so that the largest value is equal to one. The normalized curve is then displayed on the Surveillance Console.

9.7.1.3 Weighted Mean Calculation (Cross-correlation with 3.5kc target)
The weighted mean $(\bar{\theta}_i)$ for a particular pre-formed beam θ_i is defined by

$$\phi(\theta_i) = \frac{1}{2J+1} \sum_{j=-J}^{J} \alpha_i R(\theta_{i\mp j})$$

where $R(\theta_{i\mp j})$ is the stabilized detector output for the diagonal associated with beam θ_{i+j} and the weights α_i are obtained by the following device:

Let a target be on beam θ_o. If no noise is present the detector outputs are

$$R_T(\theta_i-),\; j = -J,\; -J+1,\; \ldots, J.$$

The α's are chosen so that

$$\alpha_i = R_T(\theta_i)$$

The value of J which should be used depends primarily on the beam width. This is defined as the pattern for 3500 cps.

$\phi(\theta_i)$ is computed for every beam and the resulting set of values normalized so that the targets ϕ is equal to one. The normalized curve is then displayed on the Surveillance Console.

9.7.1.4 Chi-Square Time Test
By concentrating on a particular beam and analyzing the R values obtained as a function of time, a sensitive indicator of target presence can be derived. Thus,

$$X^2(\theta) = \sum_{i=0}^{n} \left[E - R_\theta(t_i) \right]^2 / E$$

where $R_\theta(t_i)$ is the value of R for beam θ at time t_i. Used in this manner the Chi-square value can be tested for significance using a Chi-square table and thus a probability of a target being present derived.

9.7.2 Passive Classification

Detected outputs from the diagonals (beams) of a DIMUS system are at a rate which is too high for digital computer processing. It is assumed that stabilization is accomplished prior to entering the digitized DIMUS data into the computer. Since frequency analysis requires every piece of raw data at a 20KC rate to detect 10KC signals, and the raw data must be stabilized for the frequency analysis, the assumption is valid. Special purpose equipment will be necessary to do the frequency analysis as the amount of processing required is presently beyond the capacity of a digital computer.

Frequency analysis requires several multiplications for each piece of raw data. At a 20KC rate only 50 microseconds are available. The multiply speed of the fastest computers in existence is of the order of 10 micro-sec. Thus, it is seen that special purpose equipment is required.

One potentially attractive area for application of the central processor to the passive classification problem is found by recognizing that the present inability to filter out noise is the major impediment to long range classification. Noise associated with the sonar platform is as follows:

a) Ambient Sea Noise
   (i) Directional Surface Noise which is a function of sea state.
   (ii) Isotropic sea noise

b) Submarine hydrodynamic flow noise; boundary eddies, separation areas, etc.

c) Machinery noise

d) Electronic system noise; hum, grounds, crosstalk, etc., entering at the microvolt level.

Of these, the statistical characteristics of the first three may be most precisely defined and theoretically should be amenable to filtering and smoothing techniques common to communications theory.

The problem is the converse of the radar problem where signal properties are known and where signal plus noise may be treated for a least squares error solution. In this problem the noise properties are most known while the expected signal properties are not; filtering requires an adaptive reward-penalty type process.

Pragmatically, the classification operators spend 60% - 80% of effective classification time, in the filtering process for own ship's noise, on operating units.

Solving this by logical computer processes appears to be a fertile area for future work.

9.7.3 Passive Tracking

The central processor can be effectively utilized to assist in four areas of passive target tracking; a) generation of predicted target bearing, b) bearing stabilization and de-stabilization; c) ATF through bearing interpolation and d) passive tracking in range through use of the PUFFS concept. These four areas are discussed below:

9.7.3.1 Gross GTT Mode

In this mode the operator assigns the target an identification number by using the keyboard on the Surveillance Console in conjunction with the cursor control which is used to place the cursor at the bearing of the target to which the target identification is to be applied.

The keyboard is used to indicate the location of the target for which tracking is to be re-initiated. The "capture symbol" is displayed on the tracking console so that the tracking operator can look in the vicinity of B_r for the target and go into the ATF mode.

Target tracking data for as many as twelve targets can be stored for re-initiation of tracking.

To assist the operator to re-initiate automatic target tracking on targets which had previously been tracked a dead reckoning procedure is used. Upon termination of tracking the following data are preserved:

Target identification

T_t = time of termination of tracking

B_t = bearing of target at termination of tracking

$\dot{B}_t$ = bearing rate of target at termination of tracking

Upon re-initiation of tracking compute

$$B_r = B_t + (T_r - T_t)\, \dot{B}_t$$

where

T_r = time at which tracking is re-initiated

B_r = bearing to look for target at time T_r.

9.7.3.2 ATF Mode Using the Preformed Beam System

In the ATF mode it is necessary to determine the bearing of the target as precisely as possible. The bearing is transmitted to Fire Control processing to be used in the target localization solutions. Since the beam width is at least 4°, some method of obtaining a more precise bearing must be used. The following is a technique by means of which the interpolated bearing can be obtained, using the normally peaked cross correlation patterns for bearing response. (Weighted-Mean Patterns).

As a result of the cross correlation pattern, each beam, θ_i has a value of $\tilde{R}(\theta_i)$ associated with it. Let the target be at some point, within the range.

$$\theta_{-J} \leq \theta \leq \theta_J$$

A peaked pattern will result from this operation, on a threshold target. The test for bearing will be the following routine.

$$= R_{-J} + R_{-J+i} = \delta_{Ji}$$

test for sign of δ_{Ji}

at sign change: $\theta_t = \theta_i$

9.7.3.3 ATF Mode Using the Spherical System

For low S/N ratio targets the central processor may be used to supply stabilization signals to the sonar ATF circuit. Bearings are transmitted from sonar to fire control every one to two seconds. This implies a maximum of three stabilization computations every second. For destabilization, bearing rate is fed back to sonar from the central processor. The data processing requirements for these calculations are as follows:

9.7.3.3.1 Stabilization

The stabilization processes are a rotation of coordinates from the deck plane to the horizon plane as follows:

E_d = elevation in deck plane system

B_d = bearing in deck plane system

E_{io} = pitch

Z_o = roll

E_h = elevation in horizon system

B_h = bearing in horizon system

then

$$\cos E_h \cos B_h = \cos E_{1o} \cos E_d \cos B_d$$
$$+ \sin Z_o \sin E_{1o} \cos E_d \sin B_d$$
$$- \cos Z_o \sin E_{1o} \sin E_d$$

$$\cos E_h \sin B_h = \cos Z_o \cos E_d \sin B_d + \sin Z_o \sin E_d$$

$$\sin E_h = \sin E_{1o} \cos E_d \cos B_d - \sin Z_o \cos E_{1o} \cos E_d \sin B_d$$
$$+ \cos Z_o \cos E_{1o} \sin E_d$$

for which E_h is determined using $\sin E_h$ and B_h by

$$B_h = \arctan \left[(\cos E_h \sin B_h)/(\cos E_h \cos B_h) \right]$$

Since $\cos E_h > 0$ the quadrant of B_h can be determined from the signs of $\sin B_h$ and $\cos B_h$. Relative bearing is then corrected to bearing from north by using a heading correction Co. Thus

$$B = B_h + C_o$$

9.7.3.3.2 De-stabilization

Since only $\dot{B}_d$ need be transmitted to the BQS-6, the following calculations can be applied for destabilization:

$$B_d = f(B_h)$$

$$\dot{B}_d = f'(B_h)\dot{B}_h$$

where $f(B_h)$ is given by the inverse solution of the stabilization equations:

$$B_d = f(B_h) = \arctan \left[(\cos E_d \sin B_d)/(\cos E_d \cos B_d) \right]$$

and

$$\cos E_d \cos B_d = \cos E_h \cos Z_o \sin B_h - \sin Z_o \sin E_h$$

$$\cos E_d \cos B_d = \cos E_h \cos B_h \cos E_{1o}$$
$$+ \cos E_h \sin B_h \sin E_{1o} \sin Z_o$$
$$+ \sin E_h \sin E_{1o} \cos Z_o$$

then $f'(B_h)$ can be approximated numerically by computing

$$f'(B_h) = \left[f(B_h + \Delta B_h) - f(B_h) \right] \Delta B_h$$

Using $\dot{B}_h$ derived in the Fire Control Solution $\dot{B}_d$ is computed using this approximation to $f'(B_h)$.

It is assumed that the effects of $\dot{E}_h$ on $\dot{B}_d$ are not significant so that the simple approach above can be used and the value of $\dot{B}_d$ thus obtained is sufficiently accurate to be used in the automatic tracking system of the BQS-6. Under the conditions in which automatic tracking is normally used this assumption is certainly valid.

9.7.4 Passive Range Tracking

No detailed studies were conducted in this area during this phase of the work. However, one obvious use of the central processor appears potentially attractive. The PUFFS console operator function can be broken down into two distinct types: global inspection and precise matching. The first type of function should, for the time being, be left in the hands of the operator.

Many factors, mostly undefined, will enter into the inspection function, where the operator decides if a particular spike represents a target. Precise matching of either the bearing factor or the matching for range is a function better done by computer. Thus, after the global inspection, the roughly gated portion of the correllogram could be transferred into the computer where all the essential time delays can be determined. Sprocket pulses on the drum can serve as time base indicators, addressable from the digital computer, so that no synchronism has to exist between drum and computer. After the basic delays have been computed, they can be fed back to the console for monitoring by the operator.

This method will also facilitate the ATF mode for PUFFS operation as well as open the possibility of stabilizing the system.

9.8 COMMAND DATA PROCESSING REQUIREMENTS

9.8.1 Computer Functional Requirements for Command

The Command Console is the position at which summary information is displayed to assist the officer making tactical decisions and planning future action. Two major functions are performed by the computer in conjunction with the Command Console; displaying information on the Tactical Display and displaying detection probability contours on the Acoustic Detection Display.

9.8.2 Tactical Display

Information displayed on the Tactical Display of the Command Console is essentially a subset of the information displayed at the Fire Control Console. Included are

- Own ship location and course
- Target locations, courses, speeds and classifications
- Target ranges and error estimates

Controls for scale and location of own ship on the display are entered into the computer and used to control the position at which various symbols are displayed.

In addition to the above functions, the officer can enter changes to own ships and targets track and display relative positions at a future point in time based on the projected targets and own ship tracks.

The display must be driven at a rate of 20 to 40 times per second. If the display is of current positions, the data displayed is recomputed five times per second. Display of projected tracks is on request so that the data must be recomputed as requested.

9.8.3 Acoustic Detection Environment Display

The detection probability, p, is given by

$$p = \frac{1}{\sqrt{2\pi}\sigma_{S.E.}} \int_{-\infty}^{S.E.} \left[\exp -(S.E./\sqrt{2}\,\sigma_{S.E.})^2 \right] d(S.E.)$$

where (S.E.) is the "Signal Excess." The signal excess is computed by

$$(S.E.) = (L_R - L_N + L_{DI} - N_{RD} - N_S) - N_W$$

where

$L_N - L_{DI} + N_{RD}$ is measured by the ship's figure of merit equipment;

L_R = radiated target noise level (set in through console)

N_S = deviation loss (function of sonar eqpt.)

and

N_W = propagation loss (described below).

The propagation loss N_W is given by

N_W = (Spreading Loss) + (Diffraction Loss) + (Attenuation Loss) + (Bottom Loss) =

$20 \log (I_o/I) + N_{Diff.} + aR + N_B.$

The terms contributing to N_W are functions of range, depth, temperature, velocity of sound, salinity, and frequency.

The procedure followed to compute the probability of detection is to trace a ray from its source and compute N_w and p at points along the ray path. The depth and range at which p=50%, 70% and 90% are noted so that a point can be displayed on the ADED for the contours of equal probability.

The primary data upon which the calculations are based are water temperature, T, and salinity, S, as functions of depth, D. These data are obtained from the bathythermograph for depths at or above the current ship depth. For those depths below current ship depth, tables are used which have been prepared for large areas of the oceans.

The velocity of sound, V, is given by

$$V = 4422 + 11.25T - 0.0450T^2 + 0.018^2D + 4.3(S-34)$$

Starting with a ray at depth D_o, with angle of inclination θ_o, its vertex velocity V_x is given by

$$V_x = V_o/\cos\theta_o$$

where V_o is computed using the above equation. At depth D_1, the horizontal distance traveled by the ray is

$$\Delta R_1 = \left|\sqrt{V_x^2 - V_o^2} - \sqrt{V_x^2 - V_1^2}\right| / (3G_1)$$

$$G_1 = (V_1 - V_o) / (D_1 - D_o).$$

Repeating this procedure for depths D_2, D_3..., the total range, R, is given by

$$R_n = \sum_{i=1}^{n} \Delta R_i = \sum_{i=1}^{n} \left|\sqrt{V_x^2 - V_{i-1}^2} - \sqrt{V_x^2 - V_i^2}\right| / (3G_i)$$

$$G_i = (V_i - V_{i-1}) / (D_i - D_{i-1}).$$

The ratio of initial intensity, I_o, to intensity, I_n, at R_n is given by

$$I_o/I_n = -R_n(V_x/V_o)^2\sqrt{(V_x^2 - v^2)(V_x^2 - V_o^2)}\ \sum_{i=1}^{n}\Delta R_i/\sqrt{(V_x^2 - V_{i-1}^2)(V_x^2 - V_i^2)}$$

The diffraction loss, $N_{Diff.}$, at R_n is given by

$$N_{Diff.} = \begin{cases} -3.3 \log \alpha - 1.7 & \text{for } \alpha \leq 1/100 \\ 0.5 - 10 \log \alpha + 0.6 (\log \alpha)^2 & \text{for } 1/100 < \alpha \leq 10 \\ 0 & \text{for } \alpha > 10 \end{cases}$$

$\alpha = (\pi f A_1^3) / (V_o A_2^2)$

f = frequency

V_o = sound velocity at source

$$A_1 = -\frac{V_o}{3\cos^2\theta_o}\sum_{i=1}^{n}\left(\frac{1}{\sin\theta_{i-1}} - \frac{1}{\sin\theta_i}\right)/g_i$$

$$A_2 = \frac{V_o}{\cos^3\theta_o}\sum_{i=1}^{n}\left|\left(\frac{1}{\sin\theta_{i-1}} - \frac{1}{\sin\theta_i}\right) - \frac{1}{3}\left(\frac{1}{\sin^3\theta_{i-1}} - \frac{1}{\sin^3\theta_i}\right)\right|/g_i$$

in which $\sin\theta_i$ is given by

$$\sin\theta_i = \sqrt{(V_x^2 - V_i^2)}\ /\ V_x.$$

The attenuation loss, aR_S, is given by

$$aR_S = f^2\left[6.51 \times 10^{-4}\ f_t/(f^2 + f_t^2) + 2.69 \times 10^{-5}/f_t\right]R_S$$
$$+ 7.8028 \times 10^{-7}(S-34)\exp(-0.02475279T)\Big]$$

where

$$f_t = 1.23 \times 10^6 \exp\left[(-4830/(T + 459.6)\right]$$

and where f is in kc, and T is in degrees Fahrenheit,

and slant range R_S is approximated by

$$R_S = \sqrt{R_h^2 + 2rd}$$

r = no. of deep refractions

d = water depth in yards

The bottom loss N_B is determined by interpolation using the curves of N_B vs. inclination angle θ. These curves are given in Figure 5 of the Acoustic Detection Prediction Studies report. Further analysis of these curves is required to determine whether high order polynomials, exponentials, or some other function will be required to approximate them in the computer.

For each point along the ray path these corrections must be computed and the signal excess determined. Then the probability of detection is computed to see if it is one of the three values to be displayed.

As each ray is traced, depth and θ must be examined. When the depth equals the ocean depth at that point, the bottom loss term N_B is applied. The value of θ for the reflected ray is equal but of opposite sign, to the angle of incidence ($\theta_{ref.} = -\theta_{incid.}$). If depth is increasing and θ becomes zero account is taken of this deep refraction by changing the sign of θ at this point.

The above equations are applied to trace several rays in order to give enough points to plot the equal probability contours. Initial angles θ_o between plus and minus 25^o at intervals of 1^o should be adequate to determine the contours. Closer spacing of points for purposes of driving the display can be obtained by interpolation if it is found to be necessary. Intervals of ten feet in depth should be adequate along each ray. The depth interval should be at most 50 ft.

The Acoustic Detection Environment Display can display the probability of detection of a target by own ship or of own ship by a target. In the first case, the ray tracing proceeds from own ship along various rays. In the second case, the ray tracing proceeds from target ship along various rays. In the second case it is necessary to supply the

computer with manually entered estimates of N_{DI}, N_{RD}, L_S, and N_δ which are functions of target type, speed, and aspect (entered at the command station).

For the active system the detection probability is computed similarly except that

$$(S.E.) = (L_S - L_N + N_{DI} - N_{RD}) + N_{TS} - 2 N_\delta - 2N_W$$

where

L_S = source level of transmitted pulse

N_{TS} = target strength

In the active case, the Figure-of-Merit (FOM) is affected by reverberation at close ranges. The value determined by

$$FOM = L_N - L_{DI} + N_{RD}$$

is adjusted in the range of 1 KYD to 8.5 KYD as follows:

$$FOM' = FOM \; (1 - e^{-Kt})$$

where FOM' is the adjusted FOM, K is a constant, and t is a function of range R. (at R = 8.5 KYD, t = 5.3 sec.)

Selection of which of the various possibilities to be displayed is controlled at the Command Console. Once a display has been requested, the computations are done once. The computer task of driving the display at a 20 to 50 cps rate remains but the calculations do not have to be redone until a new display request is made. Since the calculations are valid for only one depth the officer may request then several depths successively to determine his own best depth for detection of targets, or, in case of avoiding detection, several depths of the target may be requested.

9.9 NAVIGATION DATA PROCESSING REQUIREMENTS

The primary navigation computations are those involved with the Ships Inertial Navigation System. The present system has special purpose computations in the form of a digital differential analyzer (DDA) section of the computer and other computations which are performed in a general purpose section of the computer.

A very detailed and careful analysis is required to determine whether the computer determined by this study can economically and effectively replace the Verdan computer in the SINS system. The computations performed in the present system indicate the magnitude of the computational task so that a description of these computations is included here. The DDA tasks, in particular, would be difficult to implement on a general purpose computer unless the computer were very fast.

Two forms of Fix computations are utilized to reset the SINS. These are Loran-C and Celestial fix. These computations must be done relatively infrequently so that the computer loading which they represent is primarily space, not time.

9.9.1 Loran-C Solution

Constants: λ_M, L_M = latitude and longitude of master transmitter

λ_A, L_A = latitude and longitude of A transmitter

λ_B, L_B = latitude and longitude of B transmitter

F, C_1, C_2, C_3

Input Variables: TDA, TDB = observed time delays of transmitters A and B respectively

λ_s, L_s = latitude and longitude from SINS

Output Variables: λ, L = true latitude and longitude from Loran-C solution

Loran-C Calculations:

1. Use λ_s, L_s as a first approximation to λ, L.
2. $\bar{\lambda}_p = 90^0 - \lambda_p$, p = A,B,M or the three transmitters

3. $\bar{\bar{\lambda}}_n = 90^\circ - \lambda_n$

4. $r_p = \arccos\left[\cos \bar{\bar{\lambda}}_p \cos \bar{\bar{\lambda}}_n + \sin \bar{\bar{\lambda}}_p \sin \bar{\bar{\lambda}}_n \cos (L_p - L_n)\right]$

5. $$\delta_p = \frac{F}{4}\left[\frac{(3 \sin r - r)(\sin \lambda_p - \lambda_n)^2}{p_1 + p_{\cos} r_p} - \frac{(3 \sin r_p + r_p)(\sin \lambda_p - \sin \lambda_n)^2}{1 - \cos r_p}\right]$$

6. $\Delta_{r_p} = C_1 r_p^2 + C_2 r_p + C_3$

7. $r'_p = r_p + \delta_p + \Delta_{r_p}$

8. $\sin Z_p = - \sin \lambda_p \sin (L_p - L_n)/\sin r_p$

9. $\frac{\delta r_p}{\delta L_n} = \sin Z_p \cos \lambda_n$

10. $\frac{\delta r_p}{\delta \lambda_n} = \cos Z_p = -\sqrt{1 - \sin^2 A_p}$

11. $$K(TDA) = r'_{An} - r'_{Mn} + \left[\frac{\delta r_A}{\delta \lambda_n} - \frac{\delta r_M}{\delta \lambda_n}\right]\Delta\lambda + \left[\frac{\delta r_A}{\delta L_n} - \frac{\delta r_M}{\delta L_n}\right]\Delta L$$

$$K(TDB) = r'_{Bn} - r'_{Mn} + \left[\frac{\delta r_B}{\delta \lambda_n} - \frac{\delta r_M}{\delta \lambda_n}\right]\Delta\lambda + \left[\frac{\delta r_B}{\delta L_n} - \frac{\delta r_M}{\delta L_n}\right]\Delta L$$

Solve for $\Delta\lambda$ and ΔL

12. Let $\lambda_{n+1} = \lambda_n + \Delta\lambda$

and $L_{n+1} = L_n + \Delta L$

and iterate until

$|(\Delta\lambda + \Delta L)| < E$

9.9.2 Celestial Navigation Calculation

Outline of method used to obtain a celestial navigation fix

1. The approximate altitude and azimuth, A_{pi} and ZA_{pi}, of the two stars on which a fix is to be based, are inserted in the computer.

2. The computer calculates the stars right ascension and declination, α_{pi} and δ_{pi}, corresponding to A_{pi} and Z_{pi}, (Eqs 1-8)

3. α_{oi} and δ_{oi}, the exact right ascension and declination of the stars are obtained by searching the star tables for the α_{oi} and δ_{oi} which most closely approximate α_{pi} and δ_{pi}.

4. α_{oi} and δ_{oi} are corrected using Besselian correction coefficients which may either be calculated or prestored in tabular form. (Eq 9-10)

5. A_{ci} and Z_{ci}, calculated altitude and azimuth, are obtained from a spherical triangle solution. SINS quantities are used for a first approximation for latitude and longitude.

6. The partial derivitives required for the expansion of A_{mi} and Z_{mi} are generated.

7. ΔL and $\Delta\lambda$ are generated by solving Eq(22) and the solution is iterated until ΔL and $\Delta\lambda$ converge to within a prespecified tolerance

8. ΔH is obtained by solving Eq(26) where $i = 1$ or $i = 2$. That is, $H\Delta$ is based on the observed azimuth of only one star.

Constants: T_o, K_1, K_2, μ, μ, E, e_1, e_2

Input Variables:

λ_s, L_s = SINS latitude and longitude

$\bar{A}_{pi}$, Z_{pi} ($i = 1,2$) Approximate altitude and azimuth of stars upon which a fix is to be based.

$\hat{A}_{mi}$, Z_{mi} ($i = 1,2$) true altitude and azimuth of stars (measured by a periscope which is effectively stabilized).

Star Table consisting of the right ascension and declination, α_o and δ_o, of stars selected on the basis of their brightness and position on the celestial sphere.

A,B,C,D Besselian correction coefficients (which may be tabulated or calculated.)

Day of Year, Time of Day.

Output Variables:

λL = Latitude and longitude of vessel as determined by fix solution

ΔH = SINS heading correction

Equations

1. $\sin \delta_{pi} = \cos \bar{A}_{pi} \cos \bar{\lambda}_s + \sin \bar{A}_{pi} \quad \bar{\lambda}_s \cos Z_{pi}$

2. $\cos \delta_{pi} = \sqrt{1 - \sin^2 \delta_{pi}}$

3. $\delta_{pi} = \tan^{-1} \left[\dfrac{\sin \delta_{pi}}{\cos \delta_{pi}} \right]$

4. $\sin t_{pi} = \dfrac{- \sin \bar{A}_{pi} \sin Z_{pi}}{\cos \delta_{pi}}$

5. $\cos t_{pi} = \sqrt{1 - \sin^2 t_{pi}}$

6. $t_{pi} = \tan^{-1}\left[\frac{\sin t_{pi}}{\cos t_{pi}}\right]$

7. $T = T_o + \frac{\text{Day of Year}}{\text{Siderial Year}} + \frac{\text{Time of Day}}{\text{Siderial Day}}$

8. $\alpha_{pi} = T + L_s - t_{pi}$

9. $\alpha'_{oi} = \alpha_{oi} + T_{\mu u} + A(K_1 + K_2 \sin \alpha_{oi} \tan \delta_{oi}) + B(\cos \alpha_{oi} \tan \delta_{oi})$

$+ C(\cos \alpha_{oi} \sec \delta_{oi}) = D(\sin \alpha_{oi} \sec \delta_{oi})$

10. $\delta'_{oi} = \delta_{oi} + T\mu' + A(K_2 \cos \alpha_{oi}) + B(-\sin \alpha_{oi})$

$+ C(\tan E \cos \alpha_{oi} - \sin \alpha_{oi} \sin \delta_{oi}) + D(\cos \alpha_{oi} \sin \delta_{oi})$

11. $t_{ci} = T - (\alpha'_{oi} - L_n)$

12. $\sin A_{ci} = \cos \delta'_{oi} \cos \bar{\lambda}_n + \sin \delta'_{oi} \sin \bar{\lambda}_n \cos t_{ci}$

13. $\cos A_{ci} \sqrt{1 - \sin^2 A_{ci}}$

14. $A_{ci} = \tan^{-1}\left[\frac{\sin A_{ci}}{\cos A_{ci}}\right]$

15. $\sin Z_{ci} = \frac{-\sin \delta'_{oi} \sin t_{ci}}{\cos A_{ci}}$

16. $\cos Z_{ci} = \sqrt{1 - \sin^2 Z_{ci}}$

17. $Z_{ci} = \tan^{-1}\left[\frac{\sin Z_{ci}}{\cos Z_{ci}}\right]$

18. $\frac{\partial A_{ci}}{\partial \lambda_n} = -\cos Z_{ci}$

19. $\dfrac{\partial A_{c1}}{\partial L_n} = - \sin Z_{c1} \cos \lambda_n$

20. $\dfrac{\partial Z_{c1}}{\partial \lambda_n} = (\sin Z_{c1}) \tan A_{c1}$

21. $\dfrac{\partial Z_{c1}}{\partial L_n} = (\sin \lambda - \sin A \sin \delta'_{c1}) / \cos^2 A$

22. $A_{m1} = A_{c1} + \dfrac{\partial A_{c1}}{\partial \lambda_n} \Delta\lambda_n + \dfrac{\partial A_{c1}}{\partial L_n} \Delta L_n$

$A_{m2} = A_{c2} + \dfrac{\partial A_{c2}}{\partial \lambda_n} \Delta\lambda_n + \dfrac{\partial A_{c2}}{\partial L_n} \Delta L_n$

23. Equations (22) are solved for $\Delta\lambda_n$ and ΔL_n.

24. $\lambda_{n+1} = \lambda_n + \Delta\lambda_n$

$L_{n+1} = L_n + \Delta L_n$

The solution is iterated until

$|\Delta\lambda_n| \leq \epsilon_1$

$|\Delta L_n| \leq \epsilon_2$

26. $\Delta H = Z_{m1} - \left(Z_{c1} + \dfrac{\partial Z_{c1}}{\partial \lambda_n} \Delta\lambda_n + \dfrac{\partial Z_{c1}}{\partial L_n} \Delta L_n\right)$

27. Besselian coefficients are given by

$A = T - k_1 \sin \Omega + k_2 \sin 2\Omega + k_3 \sin 2L + K_4 \sin(L - \gamma)$

$B = k_5 \cos \Omega + k_6 \cos 2\Omega + k_7 \cos 2L + k_8 \cos(3L - \gamma)$

$\quad + k_9 \cos 2\theta + k_{10} \cos(2\theta - \Omega) + k_{11} \cos(3\theta - \gamma')$

$CC = k_{12} \cos \epsilon \cos t$

$D = k_{12} \ln t$

$T, k_1 - k_{13}$ are constants

$\Omega, L, \gamma, \theta, \gamma'$ are single linear functions of time.

9.9.3 SINS Equations -(equation mechanization)
The basic navigation equations for the N7B Inertial Navigator are derived in EM-2140. The following list of equations are mechanized in the VERDAN computer of the N7B Inertial Navigator:

(A) DA EQUATIONS

1. Velocity Increments

(a) $dV_x = dV_x(1\text{-}6) + dV_x(7)$**

where $dV_x(1\text{-}6) = k_x A_x' dt(1\text{-}6)$

$dV_x(7) = k_x A_x' dt(7) + a_x dt + (\omega_z + \Omega_z) V_y dt^* - C\Delta V_x dt$

(b) $dV_y = dV_y(1\text{-}6) + dV_y(7)$

where $dV_y(1\text{-}6) = k_y A_y' dt(1\text{-}6)$

$dV_y(7) = k_y A_y' dt(7) + a_y dt - (\omega_z + \Omega_z) V_x dt^* - C\Delta V_y dt$

2. Angular Rates (Standard Latitude-Longitude Coordinates)

(a) $$\rho_x dt = \frac{V_y dt^*}{a}(1 - \epsilon C_{Xz}^2) - 2\epsilon C_{Xy} dC_{Xz}$$

(b) $$\rho_y dt = \frac{-V_x dt^*}{a}(1 - \epsilon C_{Xz}^2) + 2\epsilon C_{Xx} dC_{Xz}$$

*These terms are disabled when $V_r = 0$ except in DI-2
**The velocity increments are accumulated in 7 DA integrators.

3. Angular Rates (Transverse Latitude-Longitude Coordinates)

(a) $\rho_x dt = \frac{V_y dt^*}{a}(1 - \epsilon C^2_{Y_T z}) - 2\epsilon C_{Y_T y} dC_{Y_T z}$

(b) $\rho_y dt = \frac{-V_x dt^*}{a}(1 - \epsilon C^2_{Y_T z}) + 2\epsilon C_{Y_T x} dC_{Y_T z}$

4. Direction Cosines (Standard Latitude-Longitude Coordinates)

(a) $dC_{Xx} = (\rho_z C_{Xy} - \rho_y C_{Xz})dt$

(b) $dC_{Xy} = (\rho_x C_{Xz} - \rho_z C_{Xx})dt$

(c) $dC_{Xz} = (\rho_y C_{Xx} - \rho_x C_{Xy})dt$

5. Direction Cosines (Transverse Latitude-Longitude Coordinates)

(a) $dC_{Y_T x} = (\rho_z C_{Y_T y} - \rho_y C_{Y_T z})dt$

(b) $dC_{Y_T y} = (\rho_x C_{Y_T z} - \rho_z C_{Y_T x})dt$

(c) $dC_{Y_T z} = (\rho_y C_{Y_T x} - \rho_x C_{Y_T y})dt$

6. Gyro Torquing Functions

(a) x gyro: $S_x\left[\omega_y dt - \frac{K}{a}\Delta V_y dt + b_x dt\right]$

where: $\omega_x dt = \rho_x dt + \Omega_x dt$

(b) y gyro: $S_y\left[\omega_y dt - \frac{K}{a}\Delta V_x dt + b_y dt\right]$

where: $\omega_y dt = \rho_y dt + \omega_y dt$

*These terms are disabled when $V_r = 0$ except in DI-2

(c) z gyro: $S_z\left[{}_{\omega z}dt - \frac{K_z}{a}\Delta V_N dt + b_z dt\right] + \Delta\phi_z$

where: ${}_{\omega z}dt = {}_{\rho z}dt + {}_{\Omega z}dt$

7. Display Coordinates (Standard Latitude-Longitude Coordinates)

(a) $d\theta = -\rho_y \cos\alpha\, dt - \rho_x \sin\alpha\, dt$

(b) $d\lambda\cos\theta = -\rho_y \sin\alpha\, dt + \rho_x \cos\alpha\, dt$

(c) $\rho_z dt = -d\lambda\sin\theta$

8. Display Coordinates (Transverse Latitude-Longitude Coordinates)

(a) $d\theta_T = -\rho_y \cos\alpha_T dt - \rho_x \sin\alpha_T dt$

(b) $d\lambda_T \cos\theta_T = -\rho_y \sin\alpha_T dt + \rho_x \cos\alpha_T dt$

(c) $\rho_z dt = -d\lambda_T \sin\theta_T$

9. Earth Rate Components (Standard Latitude-Longitude Coordinates)

(a) $\Omega_x = \Omega C_{Xx} = \Omega\cos\theta\cos\alpha$

(b) $\Omega_y = \Omega C_{Xy} = -\Omega\cos\theta\sin\alpha$

(c) $\Omega_z = \Omega C_{Xz} = -\Omega\sin\theta$

10. Earth Rate Components (Transverse Latitude-Longitude Coordinates)

(a) $\Omega_x = \Omega C_{Y_T x} = \Omega\left[-\sin\theta_T\sin\lambda_T\cos\alpha_T + \cos\lambda_T\sin\alpha_T\right]$

(b) $\Omega_y = \Omega C_{Y_T y} = \Omega\left[\sin\theta_T\sin\lambda_T\sin\alpha_T + \cos\lambda_T\cos\alpha_T\right]$

(c) $\Omega_z = \Omega C_{Y_T z} = \Omega\left[-\cos\theta_T\sin\lambda_T\right]$

(B) GP EQUATIONS

1. Direction Cosines (Standard Latitude-Longitude Coordinates)

   (a) $C_{Xx} = \cos\theta \cos\alpha$

   (b) $C_{Xy} = -\cos\theta \sin\alpha$

   (c) $C_{Xz} = -\sin\theta$

2. Direction Cosines (Transverse Latitude-Longitude Coordinates)

   (a) $C_{Y_T x} = -\sin\theta_T \sin\lambda_T \cos\alpha_T + \cos\lambda_T \sin\alpha_T$

   (b) $C_{Y_T y} = \sin\theta_T \sin\lambda_T \sin\alpha_T + \cos\lambda_T \cos\alpha_T$

   (c) $C_{Y_T z} = -\cos\theta_T \sin\lambda_T$

(C) VELOCITY TERMS (STANDARD LATITUDE-LONGITUDE COORDINATES)

1. $V_r = k_V V_T$

2. $V_{rx} = V_r \cos(\psi - \alpha)$

3. $V_{ry} = V_r \sin(\psi - \alpha)$

4. $V = \sqrt{V_x^2 + V_y^2}$

5. $V_N = V_x \cos\alpha - V_y \sin\alpha$

6. $V_E = V_y \cos\alpha + V_x \sin\alpha$

7. $\Delta V_N = \Delta V_x \cos\alpha - \Delta V_y \sin\alpha$

8. $\Delta V_x = V_x - V_{rx}$

9. $\Delta V_y = V_y - V_{ry}$

(D) VELOCITY TERMS (TRANSVERSE LATITUDE-LONGITUDE COORDINATES

1. $V_r = k_V V_T$

2. $V_{rx} = V_r \cos(\psi - \alpha_T)$

3. $V_{ry} = V_r \sin(\psi - \alpha_T)$

4. $V = \sqrt{V_x^2 + V_y^2}$

5. $\Delta V_x = V_x - V_{rx}$

6. $\Delta V_y = V_y - V_{ry}$

(E) DELAYED THREE-FIX RESET EQUATIONS

$$\hat{\epsilon}_{h/\hat{\Omega}} = \frac{1}{2 \sin \frac{\hat{\Omega}}{2}(t_2 - t_1)} \left[\frac{\cos \frac{\hat{\Omega} t_1}{2}}{\sin \frac{\hat{\Omega} t_2}{2}} (\Delta\hat{\theta}_2 - \Delta\hat{\theta}_0 \cos \hat{\Omega} t_2) + \frac{\cos \frac{\hat{\Omega} t_2}{2}}{\sin \frac{\hat{\Omega} t_1}{2}} (-\Delta\hat{\theta}_1 + \Delta\theta_0 \cos \hat{\Omega} t_1) \right]$$

$$\left(\hat{\phi}_{20} \cos \bar{\theta} + \frac{\hat{\epsilon}_h}{\hat{\Omega}}\right) = \frac{1}{2 \sin \frac{\hat{\Omega}}{2} (t_2 - t_1)} \left[\frac{\sin \frac{\hat{\Omega} t_1}{2}}{\sin \frac{\hat{\Omega} t_2}{2}} (\Delta\hat{\theta}_2 - \Delta\hat{\theta}_0) - \frac{\sin \frac{\hat{\Omega} t_2}{2}}{\sin \frac{\hat{\Omega} t_1}{2}} (\Delta\hat{\theta}_1 - \Delta\hat{\theta}_0) \right]$$

$$(\phi_z - \phi_{z0}) = \frac{1}{\cos \bar{\theta}} \Bigg[(\phi_{z0} \cos \bar{\theta} + \frac{\epsilon_h}{\Omega})(\cos \Omega t_2 - 1) +$$

$$\sin \Omega t_2 \, (-\Delta\theta_0 + \frac{\epsilon_h}{\Omega}) \Bigg]$$

$$\epsilon_p = -\frac{1}{t_2} (\phi_z - \phi_{z0}) \sin \bar{\theta} + (\Delta\lambda_2 - \Delta\lambda_0)$$

$$\epsilon_n = \epsilon_h \sin \bar{\theta} + \epsilon_p \cos \bar{\theta}$$

$$-\Delta_{bx} = \epsilon_n \cos \alpha$$

$$-\Delta by = -\epsilon_n \sin \alpha$$

$$-\Delta by = \epsilon_z = \epsilon_h \cos \bar{\theta} - \epsilon_p \sin \bar{\theta}$$

$$-\Delta\phi_z = \left[(\phi_{z0} \cos \bar{\theta} + \frac{\epsilon_h}{\Omega}) \cos \Omega t_3 + (-\Delta\theta_0 + \frac{\epsilon_h}{\Omega}) \sin \Omega t_3 \right] \frac{1}{\cos \bar{\theta}}$$

(F) INITIAL CONDITIONS IN THE TRANSVERSE COORDINATE SYSTEM

At the moment of transformation from standard to transverse coordinates, the initial conditions for the transverse coordinate system are:

$$\lambda_{To} = 90 \text{ degrees east}$$

$$\theta_{To} = \theta_o - 90 \text{ degrees}$$

9.9.4 Rates

SINS outputs corrections to the gyros every 10 ms. The correction is one bit and five bits can be accumulated and transmitted from the SINS Navigation computations every 50 ms., with the five bits retransmitted at the rate of one every 10 ms.

The velocity meters which are input to the SINS calculations are sampled 300 times per sec. By counting, these values can be saved and transmitted to the SINS input section every 50 ms.

The general purpose calculations in SINS must be completed in 500 ms. and used to update the DDA portion of the SINS calculations.

The Loran-C and Celestial Navigation computations are performed on request. There may be several hours between requests.

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CHAPTER VIII, LIST OF PERSONS AND PLACES VISITED

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LT D.B. MacClary

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CDR G.H. Mahoney

Submarine Development Group Two

LCDR G.R. King, R.N.

Submarine Squadron 10

CDR W.E. Cummins

Submarine Squadron 14

CDR O. Kimzey, Jr.

USS SKIPJACK (SS(N)585)

LT W.C. Greenlaw

USS PATRICK HENRY (SSB(N)599) (Off-duty Crew)

LT D.M. Ulmer
LT R.T. Wright

USS THOMAS A. EDISON (SSB(N)610) (Off-duty Crew)

LCDR V.S. Lunt

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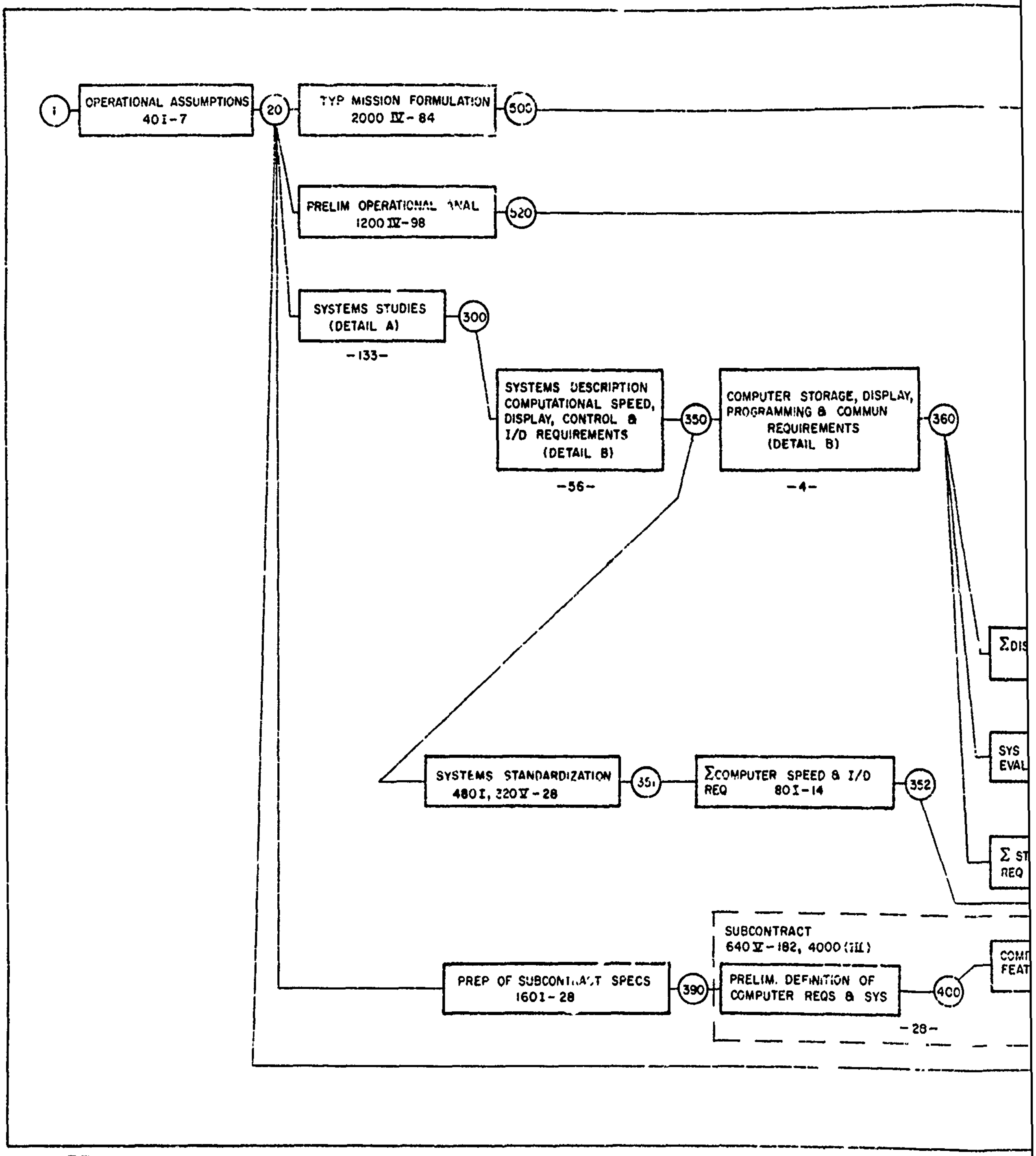
APPENDIX 1

CONCEPTUAL DESIGN STUDY

(PERT CHART)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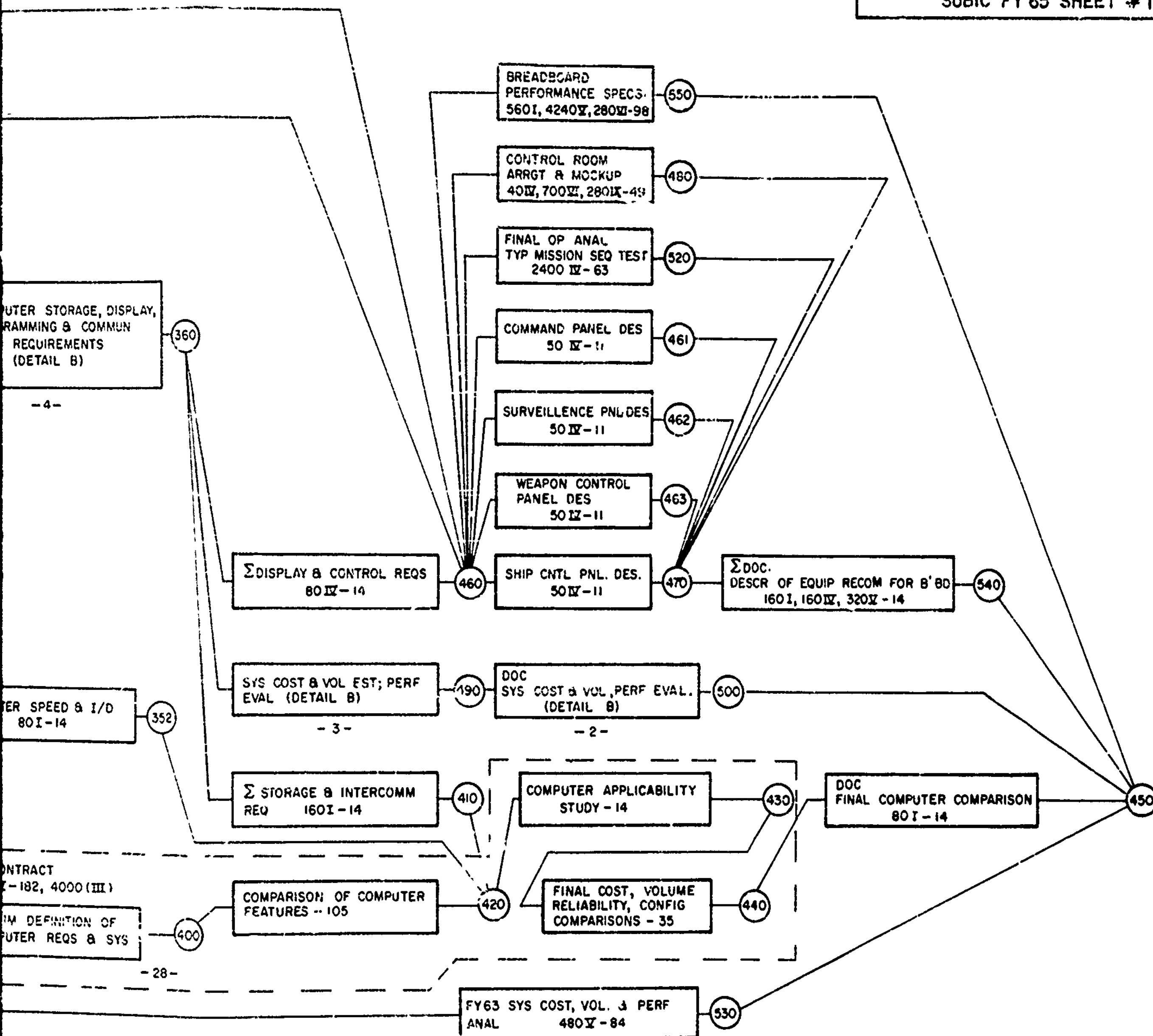

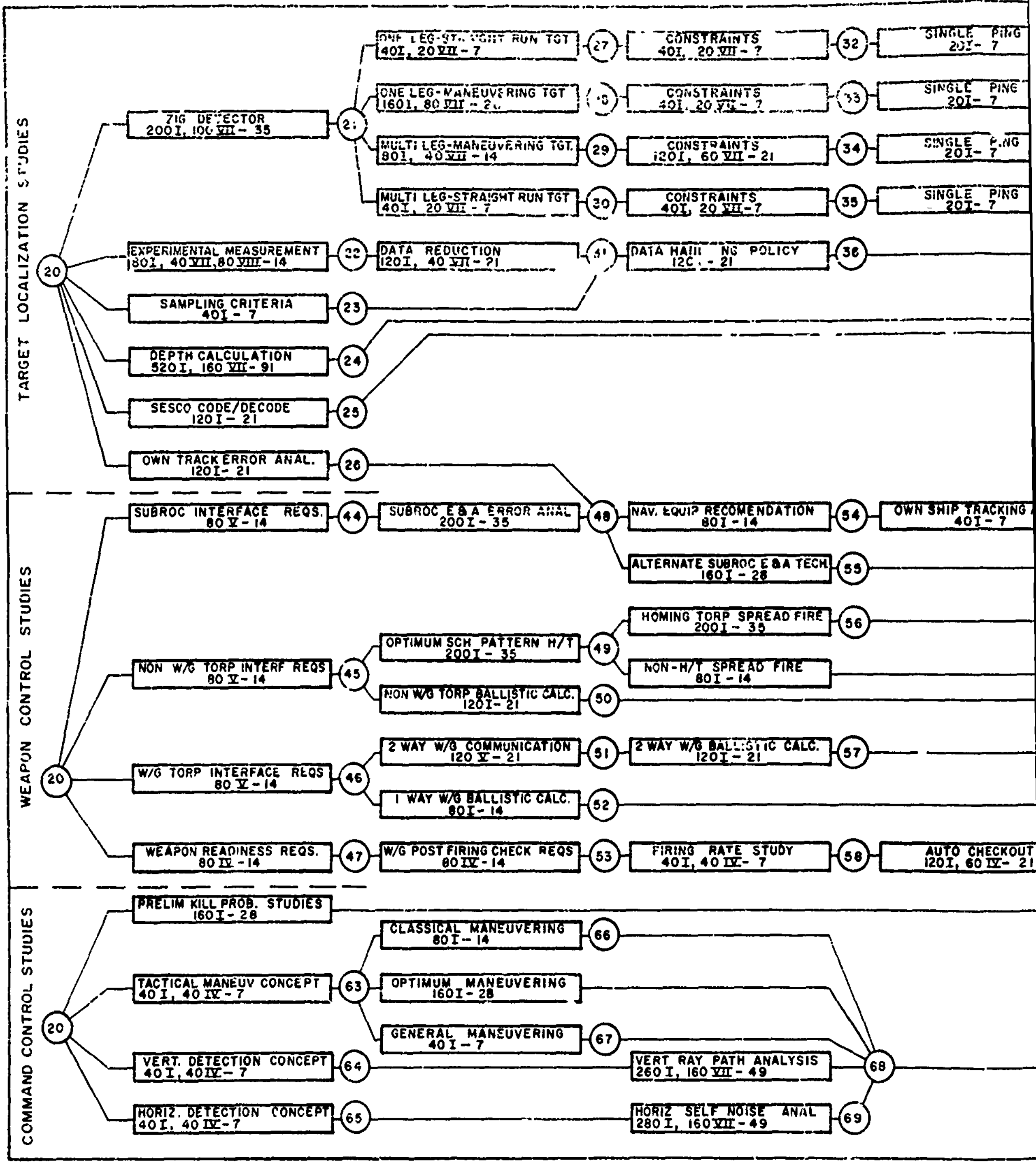
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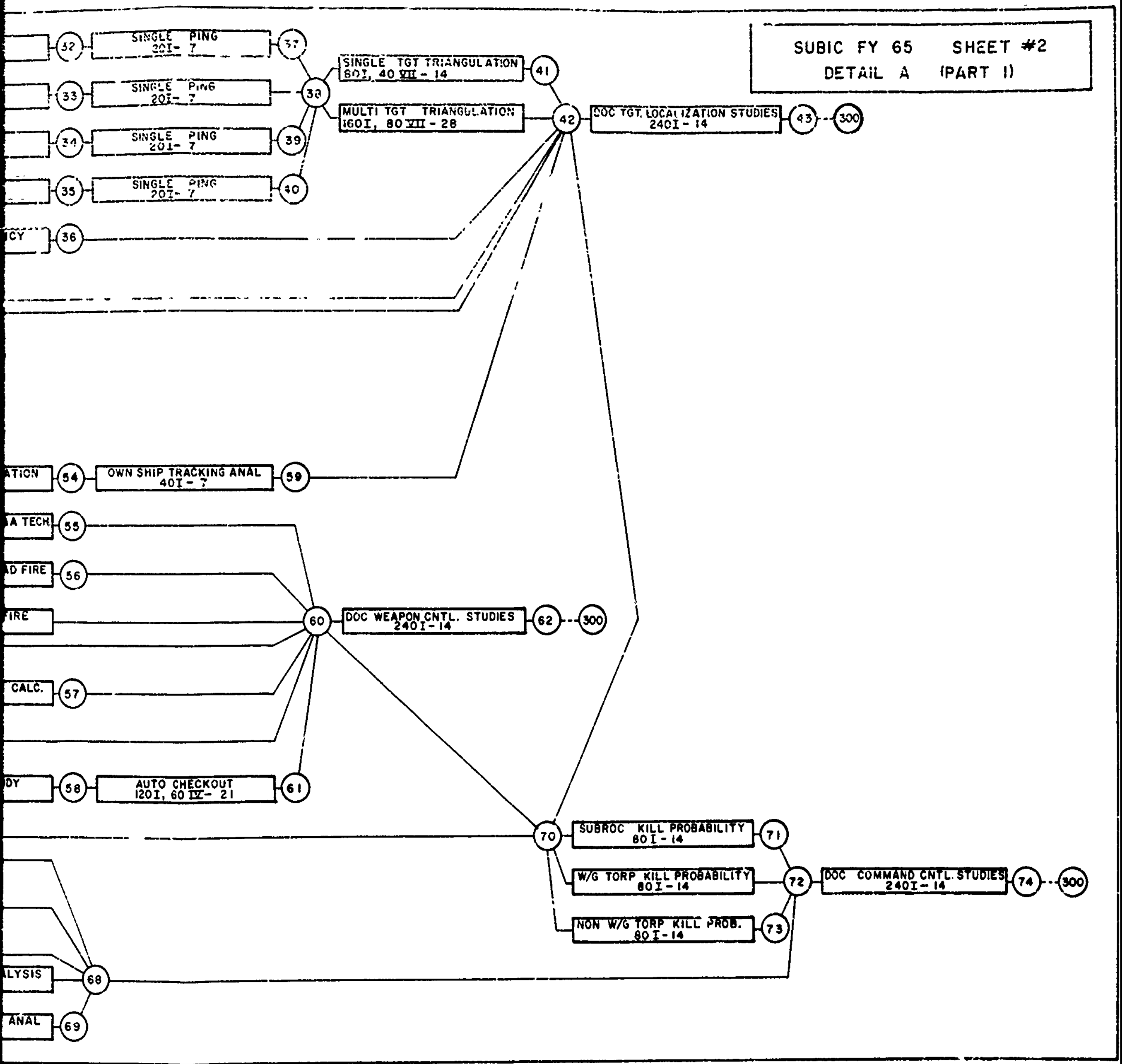

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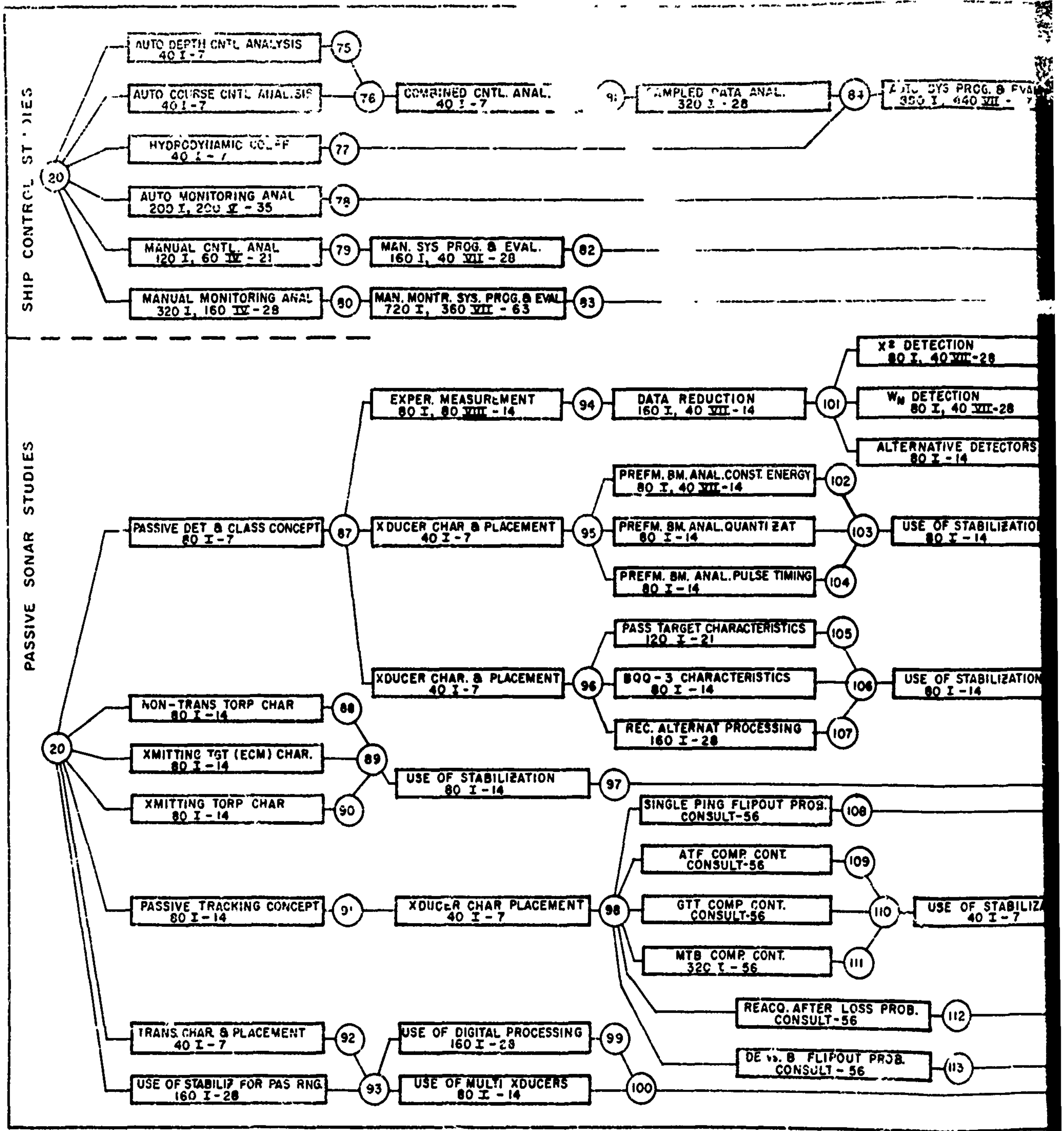
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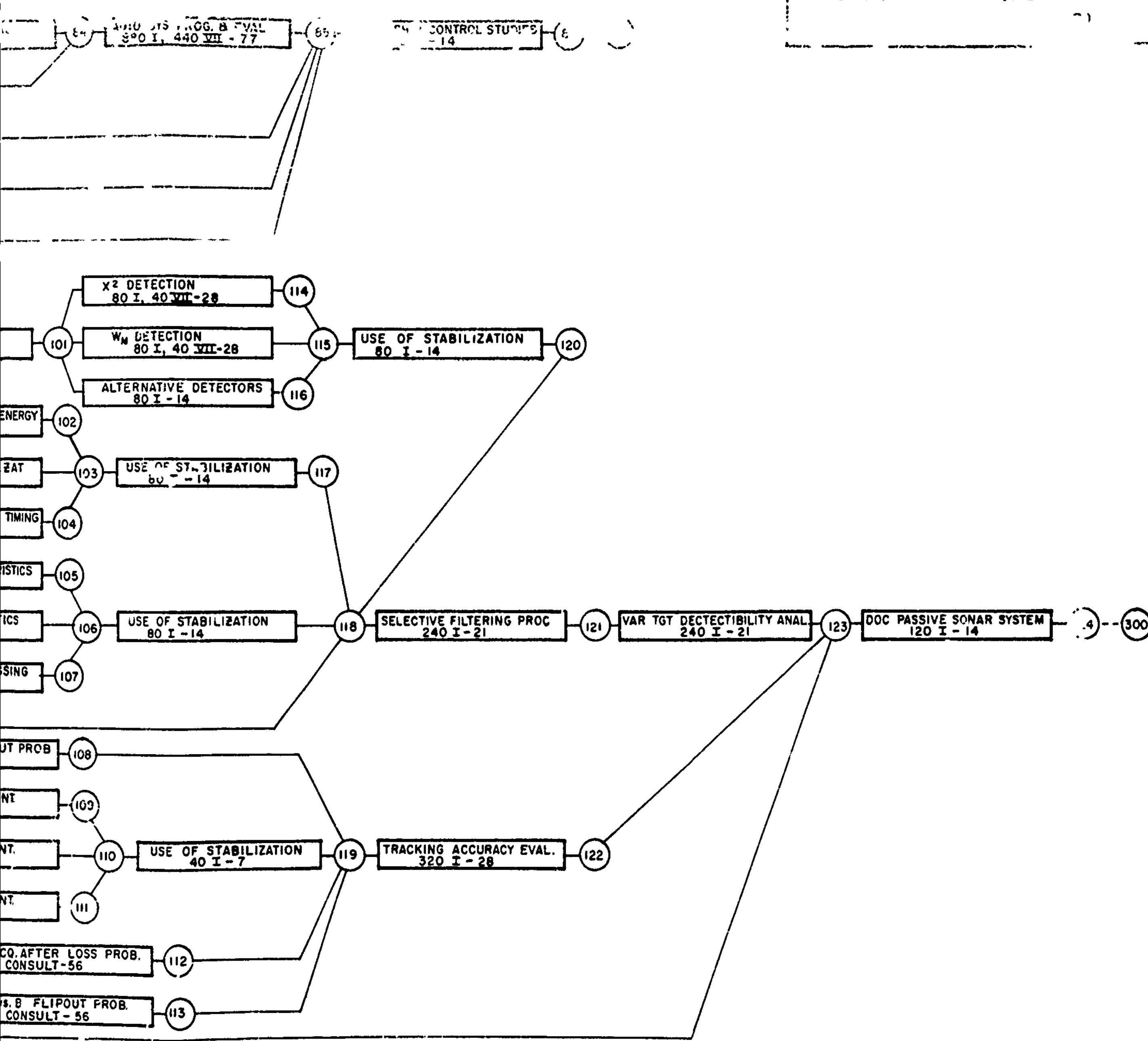

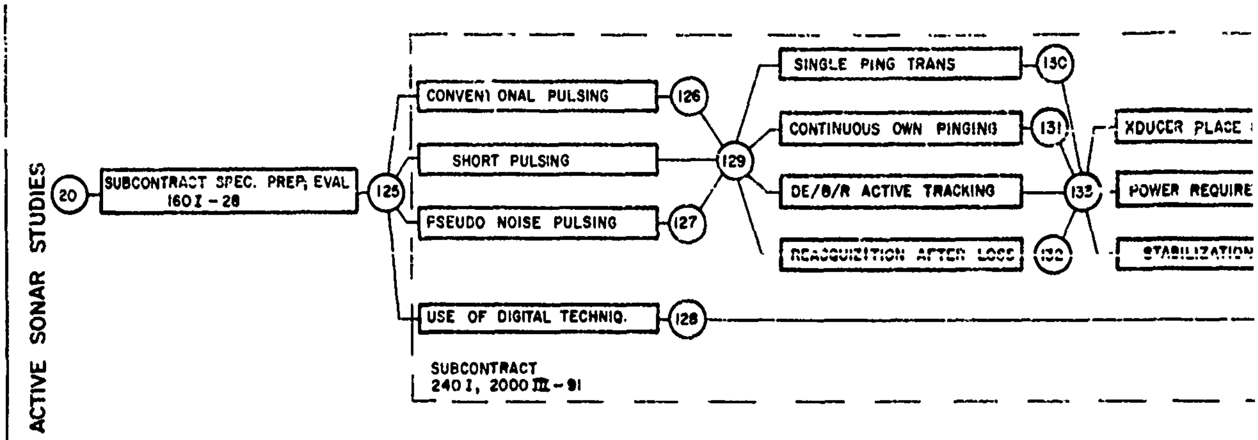

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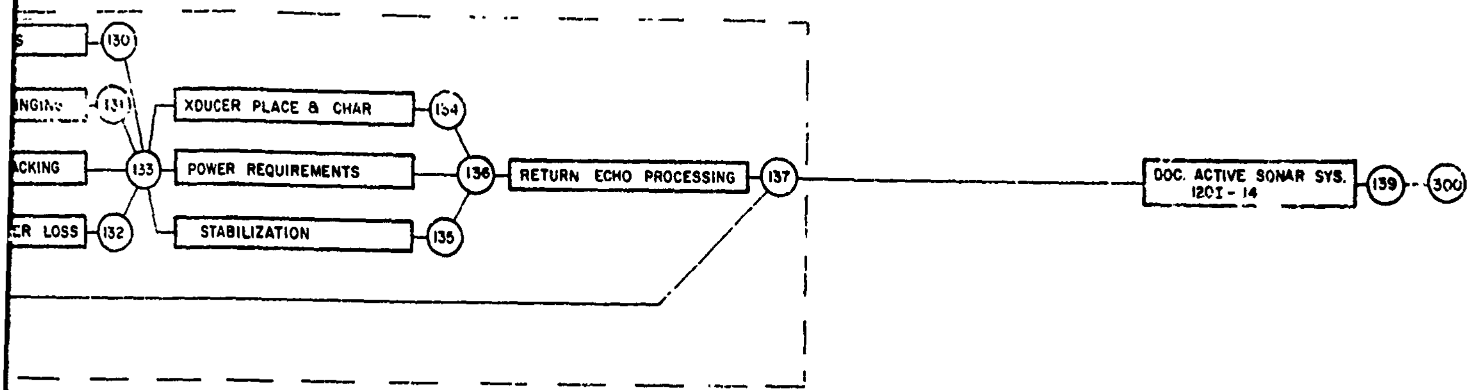

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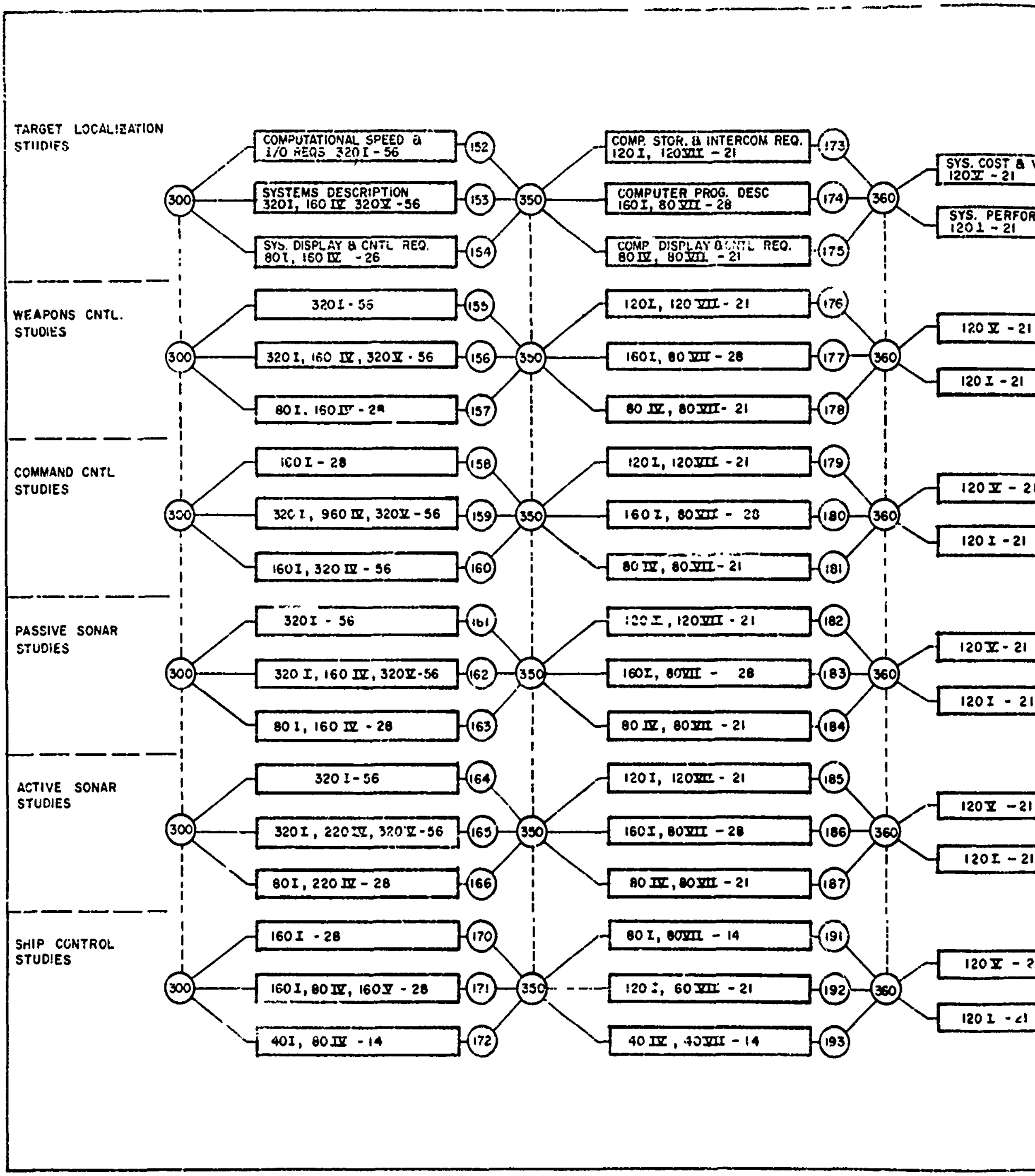
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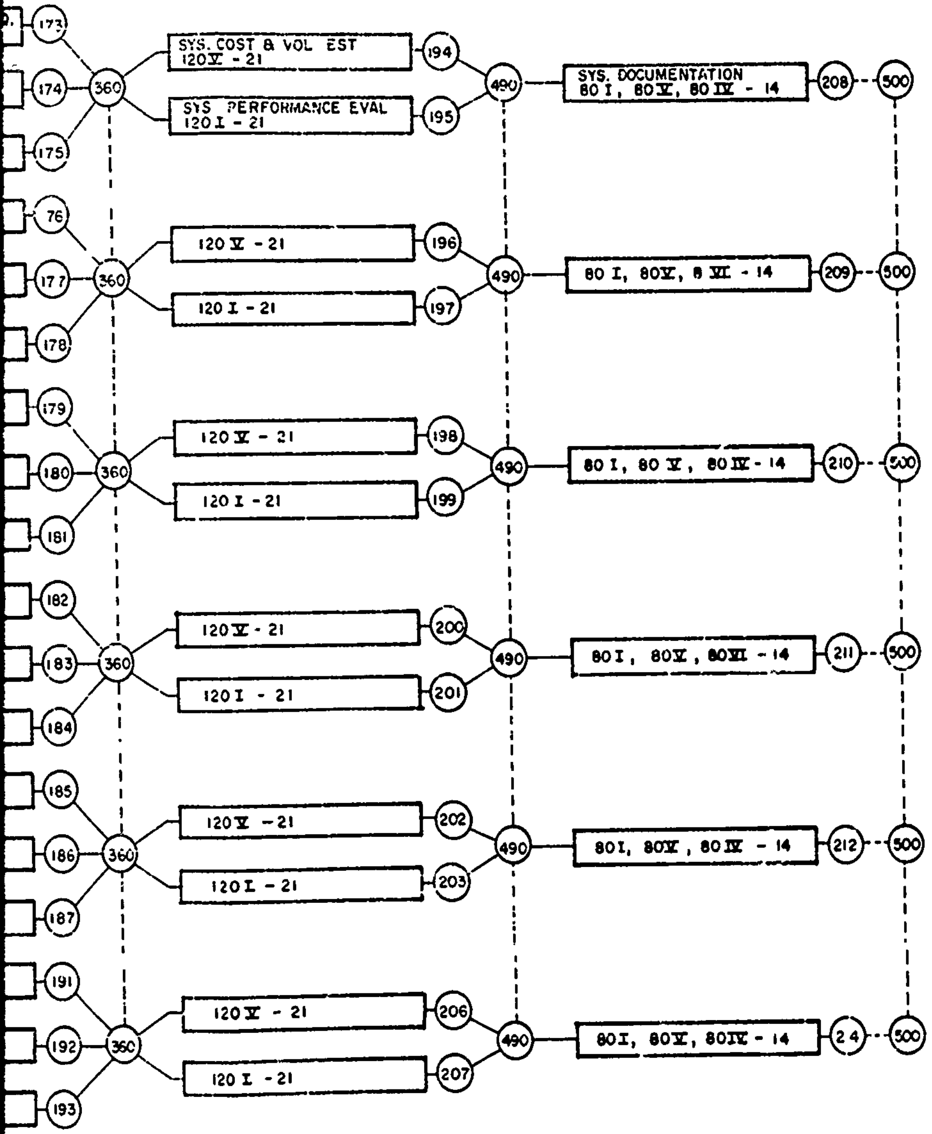

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C417-62-017
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C417-62-017
[illegible] Boat
[illegible] FY-65 ASW [illegible]
An ONR SUBIC [illegible]